HISTORY OF CONSTRUCTION CULTURES

VOLUME 1

edited by

João Mascarenhas-Mateus
and **Ana Paula Pires**

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HISTORY OF CONSTRUCTION CULTURES

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History of Construction Cultures

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History of Construction Cultures – Mascarenhas-Mateus & Paula Pires (eds)

Introduction: *History of Construction Cultures*

We are what we build and how we build; thus, the study of Construction History is now more than ever at the centre of current debates as to the shape of a sustainable future for humankind. Embracing that statement, the present work takes the title *History of Construction Cultures* and aims to celebrate and expand our understanding of the ways in which everyday building activities have been perceived and experienced in different cultures, times and places.

This two-volume publication brings together the communications that were presented at the 7ICCH – Seventh International Congress on Construction History, broadcast live from Lisbon, Portugal on 12–16 July 2021. The 7ICCH was organized by the Sociedade Portuguesa de Estudos de História da Construção (Portuguese Society for Construction History Studies – SPEHC); the Lisbon School of Architecture, University of Lisbon; its Research Centre (CIAUD); and the College of Social and Human Sciences of the NOVA University of Lisbon (NOVA FCSH).

This is the first time the International Congresses on Construction History (ICCH) Proceedings will be available in open access format in addition to the traditional printed and digital formats, embracing open science principles and increasing the societal impact of research. The work embodies and reflects the research done in different contexts worldwide in the sphere of Construction History with a view to advancing on the path opened by earlier ICCH editions. The first edition of ICCH took place in Madrid in 2003. Since then, it has been a regular event organized at three-year intervals: Cambridge (2006), Cottbus (2009), Paris (2012), Chicago (2015) and Brussels (2018).

7ICCH focused on the many problems involved in the millennia-old human activity of building practiced in the most diverse cultures of the world, stimulating the cross-over with other disciplines. The response to this broad invitation materialized in 357 paper proposals. A thorough evaluation and selection process involving the International Scientific Committee resulted in the 206 papers of this work, authored by researchers from 37 countries: Australia, Austria, Belgium, Brazil, Bulgaria, Canada, China, Dominican Republic, Ecuador, Egypt, Estonia, France, Germany, India, Iran, Ireland, Italy, Japan, Mexico, Netherlands, New Zealand, Norway, Peru, Poland, Portugal, Puerto Rico, Russia, Serbia, Spain, South Africa, Sweden, Switzerland, Thailand, United Arab Emirates, United Kingdom, United States of America, and Venezuela.

The study of construction cultures entails the analysis of the transformation of a community's knowledge capital expressed in the activity of construction. As such, Construction History is a broad field of knowledge that encompasses all of the actors involved in that activity, whether collective (contractors, materials producers and suppliers, schools, associations, and institutions) or individual (engineers, architects, entrepreneurs, craftsmen). In each given location and historical period, these actors have engaged in building using particular technologies, tools, machines and materials. They have followed specific rules and laws, and transferred knowledge on construction in specific ways. Their activity has had an economic value and belonged to a particular political context, and it has been organized following a set of social and cultural models.

This broad range of issues was debated during the Congress in general open sessions, as well as in special thematic sessions. Open sessions covered a wide variety of aspects related to Construction History. Thematic sessions were selected by the Scientific Committee after a call for proposals: they highlight themes of recent debate, approaches and directions, fostering transnational and interdisciplinary collaboration on promising and propitious subjects. The open sessions topics were:

- Cultural translation of construction cultures: Colonial building processes and autochthonous cultures; hybridization of construction cultures, local interpretation of imported cultures of building; adaptation of building processes to different material conditions;
- The discipline of Construction History: Epistemological issues, methodology; teaching; historiography; sources on Construction History;
- Building actors: Contractors, architects, engineers; master builders, craftspeople, trade unions and guilds; institutions and organizations;

- Building materials: Their history, extraction, transformation and manipulation (timber; earth, brick and tiles; iron and steel; binders; concrete and reinforced concrete; plaster and mortar; glass and glazing; composite materials);
- Building machines, tools and equipment: Simple machines, steam operated-machines, hand tools, pneumatic tools, scaffolding;
- Construction processes: Design, execution and protective operations related to durability and maintenance; organization of the construction site; prefabrication and industrialization; craftsmanship and workshops; foundations, superstructures, roofs, coatings, paint;
- Building services and techniques: Lighting; heating; ventilation; health and comfort;
- Structural theory and analysis: Stereotomy; modelling and simulation; structural theory and structural forms; applied sciences; relation between theory and practice;
- Political, social and economic aspects: Economics of construction; law and juridical aspects; politics and policies; hierarchy of actors; public works and territory management, marketing and propaganda;
- Knowledge transfer: Technical literature, rules and standards; building regulations; training and education; drawings; patents; scientific dissemination, innovations, experiments and events.

The thematic sessions selected were:

- Form with no formwork (vault construction with reduced formwork);
- Understanding the culture of building expertise in situations of uncertainty (Middle Ages-Modern times);
- Historical timber constructions between regional tradition and supra-regional influences;
- Historicizing material properties: Between technological and cultural history;
- South-South cooperation and non-alignment in the construction world 1950s–1980s;
- Construction cultures of the recent past: Building materials and building techniques 1950–2000;
- Hypar concrete shells: A structural, geometric and constructive revolution in the mid-20th century;
- Can engineering culture be improved by construction history?

Volume 1 begins with the open session “Cultural translation of construction cultures” and continues with all the thematic sessions. The volume ends with the first part of the papers presented at the open sessions, organized chronologically and the introductory texts by the chairs for each thematic session. Volume 2 is dedicated to the remaining topics within the general themes, also in chronological order.

Four keynote speakers were chosen to present their most recent research results on different historical periods: Marco Fabbri on “Building in Ancient Rome: The fortifications of Pompeii”; Stefan Holzer “The role of temporary works on the medieval and early modern construction site”; Vitale Zanchettin “Raphael’s architecture: Buildings and materials” and Beatriz Mugayar Kühl “Railways in São Paulo (Brazil): Impacts on the construction culture and on the transformation of the territory”.

The editors and the organizers wish to express their immense gratitude to all members of the International Scientific Committee, who, despite the difficult context of the pandemic, worked intensively every time they were called on to give their rigorous evaluation of the different papers.

The 7ICCH was the first congress convened under the aegis of the International Federation of Construction History, founded in July 2018 in Brussels. Therefore, we are also very grateful to all the members of the Federation, composed of the presidents of the British, Spanish, Francophone, German, U.S. and Portuguese Societies and its Belgian co-opted member. A special thanks is due for all the expertise and experience that was passed on by our colleagues who have been organizing this unique and world significant event since 2003, and in particular to our predecessors from all the Belgian universities who organized 6ICCH.

The editors wish to extend their sincerest thanks to authors and co-authors for their support, patience, and efforts. This two-volume work would not exist but for the time, knowledge, and generosity they invested in the initiative.

Our sincere thanks also go out to Kate Major Patience, Terry Lee Little, Kevin Rose and Anne Samson for proofreading every paper included here, and to the team at Taylor & Francis (Netherlands), in particular Germaine Seijger and Leon Bijnsdorp.

Finally, we are grateful to all members of the Local Committee and to the institutions that have supported both the 7ICCH event and the publication of these proceedings.

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João Mascarenhas-Mateus and Ana Paula Pires

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Open session: Cultural translation of construction cultures

History of Construction Cultures – Mascarenhas-Mateus & Paula Pires (eds)

On the construction of Byzantine vaulted systems through the eyes of the 19th century French rationalists

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ABSTRACT: The investigation on the Eastern features of Western medieval architecture has been complex and intricate since the early 1800s, when an increasing number of scholars became interested in the origins and development of Romanesque and Byzantine buildings. This is still an open issue: several hypotheses attempt to find a relationship between medieval architectures of the East and the West, as well as an explanation to their construction processes, deepening the scarce and sometimes hardly comprehensible historical and archaeological documentation, today available. More in-depth, through the specific treatment of the 19th-century French studies on the Byzantine domes, squinches and pendentives, the present contribution aims to understand how these constructive elements were analyzed by French rationalists. In this way, it will be possible to evaluate the plausibility of the statements they adopted, first to study them and then to expose them to a more erudite audience.

1 INTRODUCTION

In 19th-century Europe, innovation and scientific progress induced the elite scholars to gradually feel the need to categorize architectures by epoch and style. Furthermore, at the turn of the century, there began a progressive revaluation of the so-called Dark Ages from the political as well as the religious point of view. This period was no longer read in opposition to Classical flowering, but as its natural development. Thus, historians, travelers and architects became interested in exploring medieval architecture: they investigated Gothic at first and, subsequently, defined and analyzed Romanesque buildings (Crippa 1994). The Byzantine tradition, profoundly rooted in the still unexplored Orient, took more time to be considered. Due to political instability (Ronchey 2002), the Eastern European countries did not have the opportunity to study their own tradition, which at first became an object of interest by travelers coming from the West. The reconsideration of Byzantium in fact led the Germans to believe that their medieval traditional painting came from the East, that many of the churches built by Charlemagne's successors in the Rhineland were Byzantine. The French instead called Byzantine those buildings we now define as South-Western Romanesque (Saint-Front cathedral of Périgeux is the most representative), whereas the British used this term for the Saxon and Norman churches (Bullen 2003). Within this context, Byzantine constructions became not only buildings to be preserved and restored, but also examples to be considered for the design of the style representative of the new epoch. More specifically, both Germans and French attributed great importance to the construction element of the dome in the Eastern tradition. The dome on the pendentives system spread throughout the medieval period, giving rise to large complex and articulated spaces, which were not separated by perimeter and continuous masonry walls.

The question of what the origins of this system was spontaneously arose throughout the 1800s and a wide debate opened on this issue.

Especially the French, also motivated by the peculiar scheme characterizing Saint-Front Cathedral, went further: they tried to fully understand the constructive methods and practices of the so-called Byzantine architects, and formulated assumptions that sometimes misled the reader. They examined them not only focusing on the geometrical configurations and shapes, but also, starting from Eugène Viollet-le-Duc's studies, imagined the building processes, by analyzing the arrangement of their ashlars, and, considering August Choisy's work, elaborated even hypotheses on the structural behaviour.

Once we understand how these architects were interpreted by French rationalists, we will be able to critically evaluate the reliability of their statements, thus obtaining a clearer vision of the criteria they adopted, first to study them and then to expose them to a more erudite audience.

2 BYZANTIUM RECONSIDERED BY WESTERN EUROPE

2.1 *Neugriechisch – Neo-grèc*

One of the most propitious occasions for the evolution of Byzantine studies in western Europe was the meeting between Friedrich Schlegel and the Boisserée

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brothers, sons of a rich Belgian merchant and lovers of medieval art. More specifically, one of the two brothers, the architect Sulpiz Bosserée, recognized the strict relation between Greek and medieval architecture. Around 1810, he indeed coined the term *Neugriechisch*, to indicate the churches of Rhineland, which, in his opinion, belonged to the Oriental culture, and therefore, directly derived from the Hellenic tradition. Bosserée's friend, the French novelist and historian Ludovic Vitet, later translated the term *Neugriechisch* in *Neo-grèc*, and used it to indicate the French churches that, from his point of view, recalled the Byzantine culture (Brownlee 1991).

Viollet-le-Duc (1863) also took into account the concept of *Neo-grèc*: by means of this term, he defined the Byzantine culture as the evolution of Roman art revised through the Greek spirit: the Romans had the great merit to import the constructive element of the vault, later revised according to the tradition inherited by Greeks.

2.2 *Fossati brothers' and Salzenberg's drawings of Saint Sophia in Constantinople*

The reconsideration of Byzantium was not only due to the interpretation of its tradition as the direct descendent of the ancient Greek spirit.

Some far-sighted figures of the mid-1800s saw in Byzantium a rich and ideal world, to re-establish in their own countries. Among others, the King of Prussia Friedrich Wilhelm IV aimed at imitating the ancient model of Constantine's Empire, by ordering the construction of buildings according to the Neo-Byzantine style. To this aim, in 1847 he commissioned the architect Wilhelm Salzenberg a traveler in Constantinople to study the greatest example of this tradition: the church of Saint Sophia. In the same year, the young Sultan Abdul Medjid commissioned the Fossati brothers, Gaspare and Giuseppe, to restore the Constantinople church. At that time, in fact, the basilica was in decadent conditions, mainly because no substantial interventions had been undertaken after 1573. The first goal of the two brothers was to preserve the structure of the church, by strengthening walls and dome, and plumbing the inclined columns, which had suffered from seismic events and ground settlements. The year after beginning the works, some mosaics were discovered under the plaster. Gaspare Fossati, conscious of the historic importance of that discovery, published an album dedicated to the Sultan titled *Aya Sophia as Recently Restored* (Teteriatnikov 1988). Out of respect for the Muslim, he did not include in the publication any image related to the Christian religion and its symbols, but only general views of the inside and the outside of the church.

Salzenberg plugged the gap left by Gaspare Fossati and took advantage of the scaffoldings present for the restoration works, to reproduce the mosaics as accurately as possible (Salzenberg 1854).

Both Fossati's and Salzenberg's works played a very important role in the 19th century Byzantine revival: Fossati's illustrations were depicted in a surreal atmosphere, whereas those elaborated by Salzenberg documented the mosaics and decorations in detail, in order to please his king and inspire the design of modern Neo-Byzantine architectures (Figure 1). However, the goal of illustrating those images as beautifully as possible brought Salzenberg to return a state of perfection to the building, instead of representing its real condition (Bayley 2013).


(a) (b)

Figure 1. Drawings of Saint Sophia in Constantinople: (a) cross-section, (b) interior mosaics (Salzenberg 1854).

Figure 2. The Saint-Front cathedral according to the myth of Byzantine architecture in France (De Verneilh 1851).

It is therefore important to take into account the specific aim pursued by each author in the elaboration of the works.

2.3 *Saint-Front de Périgueux as the French prototype of Byzantine architecture*

Despite the Germans, the French defined Byzantine architecture present in their own country.

According to Félix de Verneilh (1851), Saint-Front in Périgueux (Figure 2) was the most prominent example of French Byzantine architecture; a copy of Saint Mark in Venice and built as an imitation of the oldest and no longer existing church of the Holy Apostles in Constantinople. By analyzing the cathedral, he tried to define the limits of the Byzantine and Romanesque traditions. The assumptions he elaborated were the result of about 10 years' travels and on-site surveys (Vitet 1853).

De Verneilh's work was also studied by Eugene Viollet-le-Duc, who in the item "Architecture" of his *Dictionnaire* designated him as "one of the most distinguished archaeologists", dedicating a large section to the oriental origins of France (Viollet-le-Duc 1854). Using material provided by the work of the French historian, Viollet-le-Duc suggested that between the Mediterranean and the East there was a line of influence that, starting from the buildings of the Rhineland in Germany, reached the Venetian colonies of Limoges around 988, a necessary step for the development of the Byzantine tradition in the domed architecture of southern France.

2.4 *British contribution to the studies of Byzantine architecture*

Unlike the French tradition, the British medieval buildings mainly showed Gothic characteristics.

Due to a lack of perception of a direct link with Byzantium, the interest in this tradition occurred much more slowly than in France and Germany. The British knowledge of Byzantine architecture was mainly based on journeys made by some members of the international Arts and Crafts movement. The mosaic technique that required great manual skills was considered very important by this group, according to which architecture and artisanship had to be closely related to each other (Crinson 1996).

The British Byzantine knowledge was also influenced by foreign travelers, like André Couchaud, who drew plans, cross-sections and elevations, accompanied by brief descriptions of some churches he visited during his trip to Athens (Couchaud 1842). Although criticized for some inaccuracies, this work was a basic and important reference text for understanding, even in an approximate and superficial way, the spread of medieval constructions in Greece. As a matter of fact, several British authors, who studied Byzantine and Romanesque architectures, mentioned the French book.

In the case of the British scholars, the study of Romanesque and Byzantine traditions aimed to further deepen the Gothic style. William Gunn (1819) coined the term "Romanesque", meant as that architecture, where the arch was the prevailing character (Waldeier Bizzarro 1992). However, a confusion among the several definitions is present, if we consider that this term was used interchangeably with "Norman" and "Byzantine", all indiscriminately adopted to identify those architectures preceding the Gothic period. It was only later that the architectural value prevailed, and thus greater importance was given to Byzantine buildings as well.

2.5 *Heinrich Hübsch and the tecnostatic proportion of the Rundbogenstil*

Among the researchers who emphasized the round vaulted element in Romanesque and Byzantine architecture, the German architect Heinrich Hübsch needs to be mentioned. More specifically, he coined the term "*Rundbogenstil*", to indicate all those constructions characterized by round arches and vaults, typical constructive elements of both medieval and new buildings. He indeed designed many churches and several public edifices and wrote many essays, among others *Über griechische Architektur* [On Greek architecture] (Hübsch 1822), which, later, brought him to the formulation of a theory about the new style *In welchem Stylen sollen wir bauen?* [In what style will we build?] (Hübsch 1828).

Thanks to the travels around Greece and Italy, he visited Greek and Roman architecture as well as the medieval buildings. In particular, he praised the tecnostatic proportions (called *Teknostatik*) of historical constructions and believed important to lend this quality even to modern architecture. The tecnostatic proportions contrasted with the architectural ones. While the latter concerned the function of the building, the former considered the structural behavior of the constructive elements in relation to the properties of their materials: every single element made of a specific material played a particular role in the whole behavior of the structure.

By means of the tecnostatic proportions, he wanted to reach the tectonic perfection typical of the Greek tradition. According to him, indeed, ancient Greeks understood quite well the structural properties of wood and properly adapted it to the trabeated system. This was not the case with Roman manners, which aimed at the appearance, rather than at the correct use of the constructive properties of structure and materials. He used the example of the Roman "engaged column", defined as the first lie in architecture (Hübsch 1828).

In contrast to ancient Romans, medieval builders understood the tecnostatic properties adopted by ancient Greeks. In fact, in Gothic and Romanesque architecture, builders mainly used small pieces of stones and bricks, the most suitable elements, to erect arches and vaults.

3 THE RATIONAL STUDY OF COUPOLE AND PENDENTIFS

3.1 *The Western misunderstanding of the Byzantine construction techniques according to Viollet-le-Duc*

The importance given to the vaulted medieval system by Hübsch's can be found also in Viollet-le-Duc's studies: according to him the medieval period was a synthesis between technique and art. For this reason, the French architect tried to outline the architectural historical theories even through structural analysis, going beyond the simple history of forms. By means of his studies, he aimed at analyzing the reasons behind the constructive processes that generated the Gothic architecture period on which he mainly focused his interest.

In relation to Byzantine buildings, resuming the concept of *Neo-grèc*, Roman influences played a fundamental role in the development of Greek-Eastern construction techniques. More specifically, ancient Romans had the benefit of having imported the construction system of the vault, then remodeled it according to the tradition inherited from the Greek people (Viollet-le-Duc 1863). The revised construction techniques were then re-proposed in the West, where

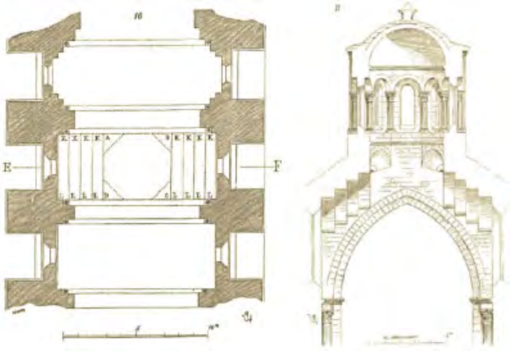

Figure 3. Notre-Dame-des-Dons ad Avignon, plan view and cross-section drawn by Viollet-le-Duc (1859).

Charlemagne had to deal with the barbarians. In the second volume of his *Entretiens*, Viollet specified that the Greeks would have developed these new principles from Syria.

Thanks to the extensive calculation and reasoning skills of the Eastern Christian people, the constructive audacity typical of the early Byzantine period could be obtained. Western builders, instead, did not fully understand the genesis of the typical Byzantine system of the dome on pendentives (Viollet-le-Duc 1859).

He justified this misunderstanding by considering that there was also a problem of hosting the Byzantine dome on pendentives in the Western churches. To explain this, he recalled the words of the archeologist and architectural theorist Quatremère de Quincy (1832), who argued that there was a "*véritable superfétation et un pléonasme architectural*" [real superficiality and an architectural pleonasm] in the juxtaposition of modern domes on the naves of the great medieval churches. Viollet-le-Duc further deepened this concept: the discordant juxtaposition was due not to the time lapse that separated the construction of the modern dome from the medieval plan, but rather to a problem of origins: the duplicity of shapes resulted in the Romanesque juxtaposition of a Roman basilica plan and a Byzantine elevation. He mentioned the example of Notre-Dame-des-Dons in Avignon, where the dome rose above a plan that was not designed to accommodate it.

The author then drew the plan and transversal cross-section of the church, to explain the "*pleonasme architecturale*" (Figure 3). It is worth noting that, by using his own words, the cathedral was at the time "*mutilée*" [mutilated]; however, he represented it with the dome.

His purpose did not deal with the documentation of the actual conditions of the church, but rather with the comprehension of the construction processes, trying to get to the roots of the logic that had led medieval builders to that specific spatial and structural conformation. The church elevation, therefore, although at that time incomplete, was the clear demonstration of the Byzantine influences in the Latin tradition.

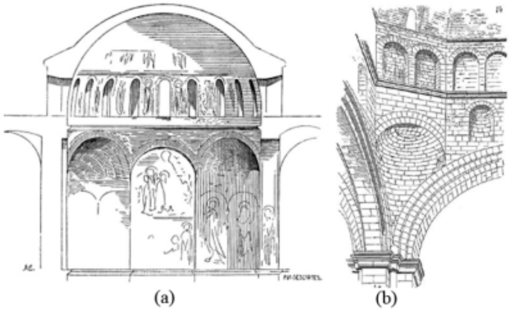

Figure 4. Detail of the "*cul-de-four*" in (a) Soteira Nykodemou in Athens; (b) Worms Cathedral (Viollet-le-Duc 1859).

In addition to the dominant element of the dome, he analyzed the French buildings, which, in his opinion, showed evident similarities with Byzantine churches: he compared, for example, the cathedral of Worms to the church of Soteira Nykodemou in Athens. In this case, the connection between Western Romanesque forms and Eastern Byzantine was present in the constructive element of the "*cul-de-four*". Four squinches, arranged at the corners of the square plan, generated by the intersection of the two arms of the cross, allowed the transition from the square to the octagon, crowned by the dome at the top. In the case of the Athenian church, the shape of the shell was hemispherical and had a continuous surface, while in the French cathedral it was internally divided in eight segments (Figure 4). The obvious constructive difficulty did not allow Western builders to erect a continuous hemispherical surface, where the transition from the square to the circle was complete.

In the different constructive practice that distinguished Western architects from Oriental, Viollet-le-Duc saw a problem related to the lack of skills that prevented the perfect implementation of the Oriental schemes.

Through the analysis of the construction technique, the French architect was thus able to demonstrate the incompetence of Western workers to assimilate the practical Byzantine constructive methods. This reasoning was also present in his analysis of the above-mentioned Saint Front Cathedral, characterized by a system of five domes, crowning the central Greek cross plan. At that time, however, numerous additions hid the perception of the Byzantine scheme: the 18th-century roofing system and transformations of the façade. Considering such a peculiar spatial and constructive configuration, it is clear why, in the mid-19th century, architects, archaeologists and builders agreed to remove the roofs that masked its structure.

In 1854, Paul Abadie, architect of the Dioceses of Périgueux, Angoulême and Cahors, began the restoration works on the cathedral. The construction site began from the south side, in particular in the reconstruction of its pillars, which, at about one third of their height, showed a marked out-of-plumb, which compromised the stability of the dome above. Once the work on that part was completed, Abadie focused on the north side, replacing the pillars, which were also seriously compromised. At that point, Leonce Reynaud, chief engineer at the Administration des Ponts et Chaussées, declared that it would not be prudent to leave the north dome in those conditions and recommended its demolition. Nevertheless, once this was touched too, a sort of domino effect triggered, which involved the demolition and reconstruction of all the domes. Abadie justified the strong choices of reconstruction using structural reasons. He observed that the pillars supporting the domes were unstable, thus accusing the medieval perigord workers of technical inexperience. From the start, they did not take into account the lowering, which the pillars were subjected to, because of the presence of the masonry domes (Laroche 1988).

Viollet-le-Duc defended Abadie's reconstructions that in 1864 were already accomplished and clearly visible, works that he himself accepted as general inspector of diocesan buildings: to justify the result, he stated that it would have been childish to reproduce a vicious disposition of pillars and that such an error had to be solved.

He explained this in two articles in his *Dictionnaire Raisonnè de l'architecture*: "Couple" and "Pendentif", significant for understanding the judgments on the technique of making pendentives by the medieval builders of Saint-Front.

In the first writing, the author thus analyzed the example of Périgueux by linking it to the great models of Oriental tradition and explaining it through descriptive geometry. The item was published in 1859, when the choice of reconstruction described above seemed definitively adopted, but the most tangible results of this decision, the new domes, were not yet visible. On this occasion, Viollet noted that a great difference between the church of Saint-Front and that of Saint Mark was present in the curvature of the vaults: while the Venetian domes had a hemispherical shape, the perigord ones were pointed. Furthermore, the pendentives, instead of being perpendicular to their curvature (in M in Figure 5), were cantilevered (in N). The ogival shape was certainly elaborated to obtain greater resistance of the supports and a lower horizontal thrust acting on them; however, in Viollet-le-Duc's opinion, Westerners never fully understood the dome system on pendentives.

In the same *Dictionnaire*, published in 1864, under "Pendentif", the criticism of barbarian artists turned into disappointment with the work of a single master builder, who did not fully understand the Byzantine construction technique and built pendentives only in appearance.

This inaccuracy in the brick arrangement by barbarian Romanesque builders was due to their lack of understanding of the refined Byzantine techniques.

Considering the rationalist point of view, it is clear that everything that could have been considered as a constructive defect in medieval construction could deviate from the theoretical model, both in terms of geometry and in terms of construction.

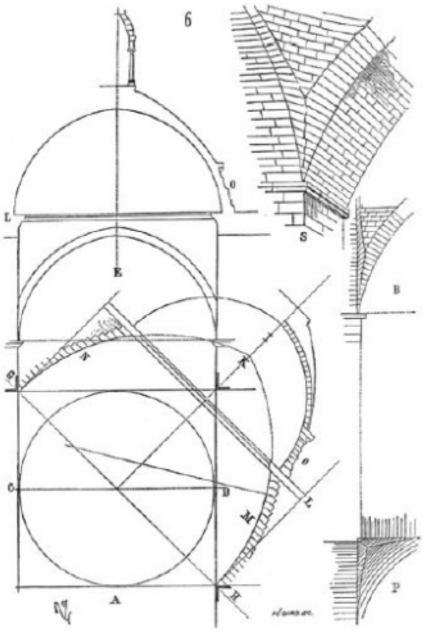

Figure 5. Section of a dome of Saint-Front in Perigeux and hypothesis of arrangement of the ashlars of the pendentives according to Viollet-le-Duc (1859).

3.2 *August Choisy's constructive analysis of the Byzantine dome*

Even the French engineer Auguste Choisy (1883) focused his studies on Byzantine vaults, initially deepened during the six-month mission at the Administration des Ponts et Chaussées in 1875 (Mandoul 2008). In this way, he had the opportunity to analyze the Byzantine churches of Athens and Salonicco.

Choisy's direct surveys of Byzantine buildings allowed him to visualize graphically what Viollet-le-Duc expressed in his speeches. The rich iconographic apparatus he published counteracted the paucity of images of the *Entretiens* concerning Byzantine architecture (Talenti 2009).

By means of the rational theories inherited from Viollet-le-Duc, he tried to hypothesize and explain the construction methods of the Byzantine structures (Choisy 1883). In this way, he could understand the method of laying these vaults and elaborate some general theories, according to which the vaults and their geometry played a key role in the whole construction process (Huerta 2009).

Figure 6 shows some diagrams drawn to explain the method of laying bricks, to build the curvature of the vaults and hemispherical niches. Hence, we can see that the bricks were not arranged radially with respect to the arch of the circumference of the curvature, but followed the rule that Choisy tried to identify. The squinches, which rose from the lateral arches, were characterized at their base by horizontal courses of bricks that were gradually replaced by oblique-fired bricks. According to Choisy, it seemed natural to make

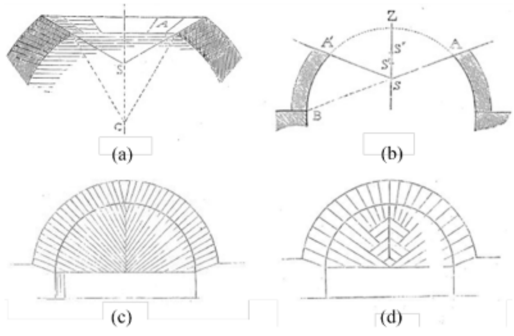

Figure 6. Studies on the arrangement of bricks in hemispherical niches present in the so-called Byzantine tradition: (a) an axonometric and (b) a schematic representation on the progressive method of building ashlars; (c) a frequent solution in the Byzantine buildings of Athens; (d) a variation of the Athenian solution, present in Saint Mark in Venice (Choisy 1883).

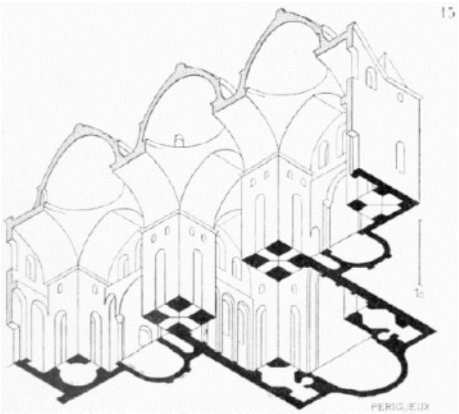

Figure 7. Saint-Front de Périgueux axonometric view (Choisy 1899).

the beds trend towards the very center of the sphere, that is to say towards point C in Figure 6(a). However, the Byzantines always transferred the tops of the cones of beds to points such as S located above the center C. In fact, if the generatrices of the bed cones all tended towards C, it would have been practically impossible to build the top of the vault. To ease the work, there was a great advantage in reducing the inclination of the generatrices by moving the top from C to S. There was even an important advantage from the point of view of thrusts. Choisy assimilated the thrust developed by the upper portion of a dome, to the force of a heavy cone: the more acute the angle S, the greater the thrust exerted by this conical wedge was. Thus, by accomplishing the vault, the top S of the bed cones came to S’, then to S” (Figure 6(b)). In Figure 6(c) Choisy represented a solution typical of the buildings located in Athens, whereas the squinch present in Figure 6(d) was a variation observable in Saint Mark in Venice.

Some years later, he published also the two volumes of *Histoire de l’architecture* (Choisy 1899), where he resumed the concepts elaborated in the previous work *L’art de bâtir chez les Byzantins*, and referred to some of the same architecture analyzed by Viollet-le-Duc under “Pendentif” and “Coupole” of his Dictionary: among others, the aforementioned Saint-Front Cathedral.

In the description of the domes, he explained that Westerners took care to stiffen the slopes of the roofs to ensure the flow of water; however, he did not cite the previous pitched roof, removed by Abadie half a century earlier. Furthermore, he represented the church with the five domes (Figure 7), referring to the restored condition as if it was the Byzantine one. Nonetheless, he referred to some modifications to the church, which, unlike his contemporaries, he did not appreciate: using his own words, “*malheureusementes restaurations ont fait disparaître les éléments de critique que l’édifice lui-même pouvait offrir*” [“unfortunately restoration works erased the critical elements that the building itself could have offered”] (Choisy 1899). It seems that there is a sort of contradiction in Choisy’s work, due to the fact that he tried to elaborate general theories to categorize the Byzantine construction methods. However, deepening each case study, the historical events were not considered and the reader might be misled to think that the present described condition belonged to the original scheme, in this case, the Byzantine one.

3.3 *Corroyer’s rational assumptions on Romanesque architecture*

Another French scholar, Edouard Corroyer, approached the world of French medieval archeology and European and Middle Eastern history, attending Viollet-le-Duc’s club, the École des Chartes, the Société Nationale des Antiquaires de France and the Société de l’Histoire de l’art Français (Gloc 2005).

At the end of his life, he wrote the two important works that allowed him to trace his history of medieval architecture: *Architecture Romane* (1888) and *Architecture Gothique* (1891).

In the first of these two works, Corroyer gave great importance to Byzantine architecture, as the generator of forms that contributed to the construction of the great Romanesque buildings, from which the new Gothic structures later developed.

He then divided his work on Romanesque architecture into two parts: the first on its origins, the second on the most representative architectures. He therefore focused on Roman and Byzantine constructions, which, in his opinion, had allowed the development of Western Romanesque culture, in particular the French. In fact, given its profoundly Christian nature, it was his interest to demonstrate the Byzantine origins of the architecture of his country: the East was the cradle of Christianity, which, in turn, had directly influenced France.

He resumed Viollet-le-Duc’s studies on the Western technique of laying Saint-Front pendentives (Corroyer

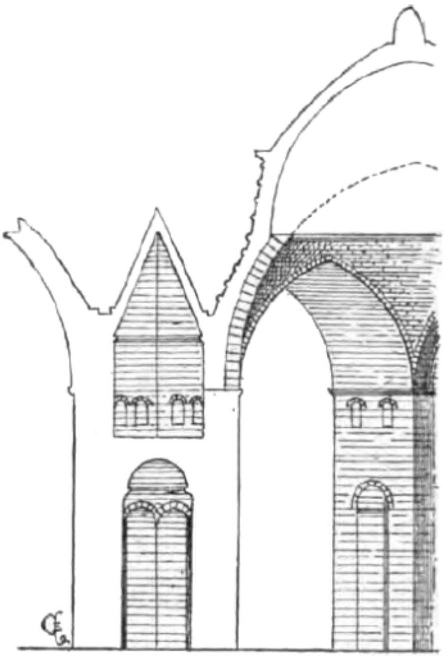

Figure 8. Saint-Front de Périgueux pendentives according to Corroyer (1888).

1888). In Corroyer's study, however, there is no reference to the horizontal arrangement, described by

Viollet-le-Duc as the existing one, and a radial trend of the ashlars was depicted (Figure 8). It is worth noting that Corroyer went beyond Viollet-le-Duc, who tried to give the building that ideal state, in which it had to be built. Corroyer, taking this concept to the extreme, modified the history of the church: he denied the preexisting arrangement of the ashlars and assumed that the scheme modified by Abadie was the Byzantine one. He considered the new pendentives as original, and elaborated the theory, according to which the vault (*croisée d'ogives*) was born from the principle of construction concerning the pendentives of Saint-Front (Gloc 2005).

In the same essay, Corroyer also reported a rather questionable drawing of the cross-section of the Byzantine Venetian church of Santa Fosca on Torcello Island, where there was a hemispherical dome crowning the central space, in place of the current wooden roof (Figure 9). The text that accompanied the picture confirmed that the dome was still there, visible to anyone. The accuracy of the description of the building suggests that he saw the church, however, the reliability of the image and the description can be easily contested: in the period in which the work was published, the dome did not exist, and, indeed, it was not even known if it had ever existed.

Delving into the issue, we discover that the same cross-section was published a few years earlier, in the work written by Hübsch (1863). The German essay was translated into French three years after in the publication *Monuments de l'architecture chrétienne: depuis Constantin jusqu'à Charlemagne et de leur influence sur le style des constructions religieuses aux époques postérieures* [*Monuments of Christian architecture: From Constantine to Charlemagne and their influence on the style of religious construction in later periods*] by Guerber (Hübsch 1866).

Figure 9. Santa Fosca cross-section with the assumed dome (Corroyer 1888).

Hübsch, however, unlike Corroyer, admitted the lack of the dome, which, if existent, must have collapsed in a previous period. Furthermore, the German author confessed that his knowledge on Venetian buildings needed to be deepened and mentioned the works of Selvatico (1847) and Mothes (1859), as reference texts, for a better knowledge on the subject. In turn, both Selvatico and Mothes referred to the wooden roof that dominated the central internal space, leaving open the question of whether or not an original dome had ever existed.

Hence, in this case, through Corroyer's essay, the ambiguity of the rational point of view is taken to its extreme consequences.

4 CONCLUSIONS

In the 19th century, there were three main reasons that led Western Europeans to the study of medieval, and in particular of the Byzantine, architectures. The first concerned the nationalist spirit which generated the desire to elaborate a national style through the study of historical constructions. The second was the desire to restore these architectures, sometimes bringing them back to their original condition, sometimes accomplishing them according to the style they deduced as original. The third explanation was related to the growing possibility of traveling and the greater interest in Oriental medieval works, still little known at the time. Especially the rationalist French scholars, also inspired by the presence of Saint-Front Cathedral with the typical so-called Byzantine scheme, tried to understand the constructive reasons and methods of such architects. With their detailed analyses on medieval buildings, Viollet-le-Duc at first and Choisy afterwards provided an important contribution to the matter. However, today the lack of clarity and truth emerges, given by the desire to describe an architecture that often corresponded to an ideal condition, perhaps original or perhaps which never existed. Depending on the author's purpose, the need to provide a theoretical model is stronger than the necessity to provide historically founded information. Salzenberg, for instance, aimed at elaborating some drawings that painted Hagia Sophia in a perfect and ideal condition: his goal did not deal with providing a scientifically valid study. The same can be said for Corroyer's work where the ideal condition of the architecture, analyzed in the present contribution, and the theoretical arrangement of the constructive elements overrode the desire to describe the reality and deleted part of their history.

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History of Construction Cultures – Mascarenhas-Mateus & Paula Pires (eds)

Style and stone – Stonemasonry in Switzerland between the Gothic and Renaissance

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ABSTRACT: In Switzerland, the Italian influence is evident since the 16th century, mostly through characteristic style features like rusticated facades and arcade courtyards, while churches kept a Late Gothic character. Are there stone working techniques and tools that are specifically related to an architectural style or is the processing dependent on the material? Building in a certain style or implementing stylistic elements is certainly decided by the architect or client. The material used for the buildings, on the other hand, is usually tied to the local stone deposits. It therefore seems plausible that stonemasons used techniques which depend on the type of stone rather than on the style of the building. This survey investigates this correlation between style and stone using specific examples of sandstone and limestone.

1 INTRODUCTION

The 16th and 17th centuries are of particular architectural interest in Switzerland, as buildings were still being built in Gothic style while new stylistic features from Italy were being incorporated in Swiss architecture. Stone working and the processing techniques have been discussed in detail by Karl Friedrich (1932), Bessac (1986), Doperé (2018) and Völkle (2016), among others, based mainly on the examples in Germany, France and Belgium. These provide fundamental knowledge, especially for the medieval period, on how the stone material was extracted from the quarries and transported to the construction sites, as well as which work steps were involved and what tools have been used by the stonemasons. Some of these studies also include investigations regarding the dependency of the material on tools and working techniques. They prove that for the regions mentioned above, the use of certain tools can, in fact, be related to the material properties of the stone type. Similar studies in Switzerland are insufficient.

To investigate the stone working traces visible on the stone surfaces and to evaluate if a dependency of material and used tools can be traced for Swiss buildings, examples from two cities, Lucerne and Solothurn, whose architecture is dominated by different types of stone, will be examined.

The buildings in Lucerne are mainly built of local gray sandstone, which is a fairly soft material that is rather easy to work with. Three buildings serve as examples. The Gothic Franciscan church, built in the 13th century, shows the restrained spatial program of mendicant churches. The arcade supports were renewed in the 16th century and testify to the stonework of that period. The Ritter'sche Palast, which was built in the middle of the 16th century, was inspired by Italian Renaissance palaces and served partially as a model for the town hall which was rebuilt at the beginning of the 17th century. In contrast, the buildings in the city center of Solothurn are dominated by Jurassic limestone and Hauterive limestone, a rock with material properties different from those of sandstone, particularly in terms of its hardness and brittleness.

Due to modifications over time, no whole buildings of "pure" Gothic or Renaissance style can be found in Solothurn as such, but a fairly large number of window jambs and portals showing both stylistic features have been preserved. The fact that some of these are made of sandstone and some of limestone makes them suitable examples for a comparative study.

2 THE GOTHIC FRANCISCAN CHURCH IN LUCERNE

2.1 *Edification and modifications of the Franciscan church*

The former Franciscan basilica is one of the very few, preserved Gothic churches in Switzerland (Meyer 1998). The history of the building has been thoroughly presented by two authors (Meyer 1998; Reinle 1953): Built from 1269 onwards, the three-aisled nave is divided by arcades, which are supported by five pairs of pillars. The long choir, with a polygonal closure, is covered by a Late-Gothic ribbed vault. The building was probably completed towards the end of the 13th century. A choir screen, used to separate the choir from the nave, was demolished in 1733 during the baroque reconstruction of the church. In the

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Figure 1. The Franciscan church in Lucerne. View on the northwestern arcades (author 2020).

period between the completion of the Gothic church and the Baroque period, several extensions and alterations were made. The most extensive interventions included the raising of the side aisles along with the enlargement of the window openings, as well as the replacement of the arcade pillars in the middle of the 16th century. The lack of symmetry between the bay openings and the windows led Reinle (1953), among others, to the assumption that the heights and spans of the arcades had been increased. Recent research, however, has shown that the arcades remained unchanged and that the bases and plinths of the supports from the construction period were used as foundations for the new pillars, which resulted in a 60 cm increase of the floor level (Hegglin & Glauser 1989) (Figure 1).

2.2 *Traces of stone working from the 16th century*

The round pillars, renewed in 1554, pass directly into the arcades without capitals. Pilaster strips are placed in front of them on all four sides. The uncovering of an original pedestal, during the renovation in 1988, showed that the columns of the construction period probably also had a similar shape (Hegglin & Glauser 1989). The pillars and pedestals are made of gray sandstone and show the traces of two different tools. The isolated, deeper punctiform holes are produced when the stonemason uses a pointed chisel (French: *broche,* German: *Spitzeisen,* Figure 2 No. 5) or a stone axe with two pointed edges (*pic de tailleur de pierre*, *Zweispitz,* Figure 2 No. 1a and b).

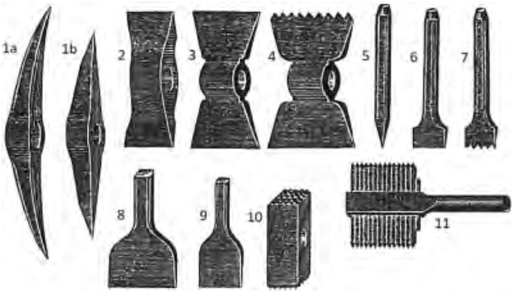

Figure 2. A selection of stone working tools. 1a and 1b: stone axe with two pointed edges. 2 and 3: stone axe with two straight edges. 4: combination tool with a straight and a serrated edge. 5: pointed chisel. 6: small chisel. 7: serrated chisel. 8 and 9: wide chisel.10: serrated stone hammer. 11: bush-hammer (Krauth & Meyer 1896; changes by the author 2020).

The pointed chisel is held and positioned by the stonemason with one hand and struck with a mallet. In contrast, the stone axe with two pointed edges is guided with both hands. Since both tools produce very similar traces on the surface, it is difficult to clearly identify them. Combination tools, with two different cutting edges (Figure 2 No. 4), enable more efficient work and were also used in the medieval period. Therefore, a tool of this kind, with at least one pointed edge, may have been used for the pedestals, as well. These tools are generally used for an initial working of the natural stone block to level its surface. The individual sections of the pillars are designed without a peripheral edge. As a next step, the roughly processed surface was smoothed with a different tool. The fine lines created by this tool run at different angles over the surfaces of the pillars and pedestals; but, within a cuboid, they are arranged regularly and mostly parallel to each other. The lines on the pillars are often very subtle so that the surface of some of the cuboids appears almost polished and the traces are only visible in lateral light. They are probably caused by a stone axe with straight edges (*marteau taillant, Glattfläche,* Figure 2 No. 2–4).

This tool has been used throughout the medieval periods for working on rather soft stones, and the stonemason wields it with both of his hands. As mentioned before, the use of a combination tool, in this case probably a stone axe with a pointed and a straight edge, would have been reasonable. This would have allowed the stonemasons to use the same tool for different work steps.

The pedestals have a square ground plan and consist of individual ashlars with narrow mortar joints. As decorative elements, they have small, triangular spurs on the four outer corners. The transitions to the pillars were carved out of the uppermost ashlars of the pedestals and show quatrefoils, pyramids and a base penetrated by a ring (Reinle 1953). All the pedestals of

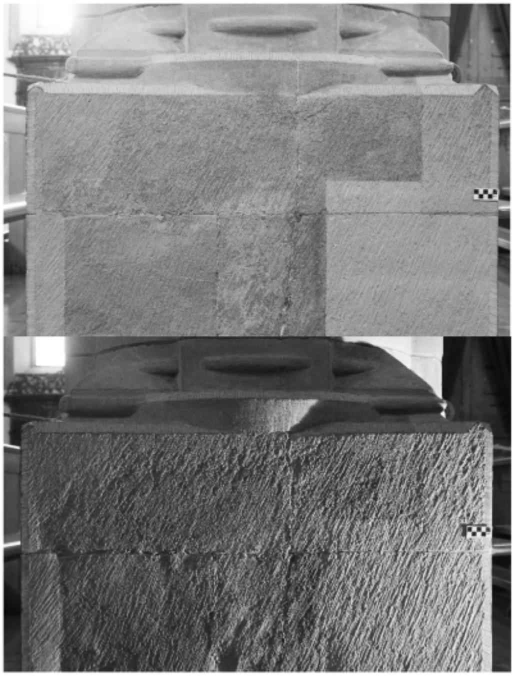

Figure 3. a (top) and b (bottom). The Franciscan Church in Lucerne. The traces on a pedestal from 1554 show the use of a stone axe with straight edges without additional light (3a) and with lateral light (3b) (author 2020).

the pillars show repaired or replaced areas whose surface treatment was adapted exactly to the older stone working. They can be clearly identified by the differentiated coloration and the more strongly defined edges and decorative elements when compared to the original areas (Figure 3a). Although some of the areas from 1554 are heavily eroded, the fine lines of the tool's cutting edge can be seen. They are 4.5–6.5 cm long. They run in parallel position perpendicular or diagonally on the surface.

The lines on the roughly 2 cm wide peripheral edge are created with a small chisel (Figure 2 No. 6) and run horizontally or diagonally, but not on every ashlar – only on the outer edges of the pedestal.

This condition makes it possible to conclude that a final processing step after the alignment of the individual cuboids was planned from the beginning. That the lines in the inner surface cross the joints of the cuboids is another argument in favor of this conclusion. According to the findings, the cuttings on the edges must have been made at a relatively flat angle with the chisel. The inner surface is shaped by fine lines running parallel to each other. Examination of the traces suggests the use of a stone axe with straight edges. The individual lines show that the stonemason guided the tool quite steeply. The observation of the lines crossing the borders of the individual cuboids mentioned above also apply to the boundaries between the renewed areas and the original ones. With a lateral light source, no major differences in processing can be detected (Figure 3b).

At virtually the same time as the late Gothic arcade pillars in the Franciscan church were built, a building with a very differentiated stylistic features was erected in the immediate vicinity, the stone working of which will be examined for comparison.

3 LUX RITTER'S PALACE IN LUCERNE

3.1 *Construction history of the palace*

Stylistically following the tradition of Italian Renaissance palaces, the Ritter'sche Palast is an important phenomenon north of the Alps. Lux Ritter received permission to build it in 1556, but he died three years later. His descendants did not want to complete the palace construction and the building was, therefore, handed over to the city of Lucerne (Reinle 1953). The building was to be completed according to the plans of master builder, Domenico Salbiolo de Ponte, and the architect, Johannes Petrus Grilietus (Giovanni Pietro del Grilio or Grieto), from Lugano, who had already been contracted by Ritter (Reinle 1953). After the city council donated the palace to the Jesuits in 1577, various building interventions followed, including the construction of a church and an extension of the building, along with the acquisition of the neighboring buildings; since 1804, the Ritter'sche Palast has been used as a government building (Reinle 1953).

3.2 *Renaissance features*

Externally, the rusticated façade on the street side is already reminiscent of the design of Italian *palazzi*. Inside, the three-story building wings with loggias open up around an originally uncovered courtyard with arcades (Reinle 1953, Figure 4).

Twelve Tuscan monolithic columns support the arcades on each floor; they are made of local, gray sandstone on the lower two floors and of wood on the top floor. Every base sits on a pedestal which, in the upper floors, functions as part of the balustrades.

3.3 *Stone working traces of the arcade pillars from 1557–64*

The columns on the ground floor clearly show the traces of the stonemason's work. Up to 10 cm-long horizontal lines run in paths around the columns (Figure 5, left side). The lengths of the lines vary because the following rows partially overlap the previous ones. Therefore, the actual blade of the tool could be slightly longer than the traces let assume. The lines are arranged in parallel, even and ordered layers, which suggest the use of a wide chisel (*charrue*, *Scharrieisen*, Figure 2 No. 8, 9). They run in circular paths around the entire column, and the overlapping lines indicate that the work was started at the top of the column, although it is safe to assume that the column was

Figure 4. The arcades from 1557–64 in the three-story inner yard of the palace of Lux Ritter in Lucerne (author 2020).

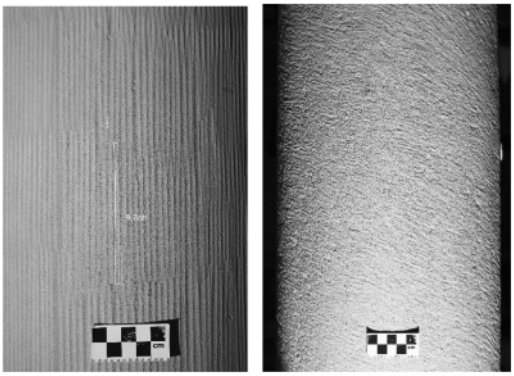

Figure 5. a (left) and b (right). The column in the ground floor (5a) of the palace of Lux Ritter in Lucerne show traces of a wide chisel. The one in the second floor (5b) show traces of a pointed chisel and a stone axe with straight edges (author 2020).

placed horizontally or at a slight angle during the work. The wide chisel, in contrast to the stone axe which is guided by both hands, is held by the stonemason with one hand and driven by a mallet with the second hand just like the narrow chisel that is used to create the peripheral edge. This provides more control over the tool and makes it possible to process the surface more evenly. As in the Franciscan Church, fine and deeper punctiform holes of the previous work with a pointed chisel or stone axe with pointed edges are visible.

The columns on the second floor also show traces of a pointed chisel. However, it seems unlikely that a wide chisel was used for the subsequent smoothing of the surface. The fine lines run around the column in different lengths, slightly diagonally.

They are so fine that they are only visible with lateral light (Figure 5b). These traces were probably created by using a stone axe with straight edges, like in the Franciscan Church.

In comparison with the columns on the ground floor, whose strongly structured surface is also a deliberate means of design, those on the second level are designed to create a smooth and unstructured effect. With the wooden columns on the third floor, the traces of the stone working reflect a hierarchical order between the floors, with descending importance towards the top.

4 THE TOWN HALL OF LUCERNE

4.1 *The new building at the beginning of the 17th century*

During construction works in 1588 (Reinle 1954), the statics of the first town hall at the Kornmarkt were so severely compromised that a new building had to be constructed. The building documents mentioned by Reinle (1954) provide evidence of discussions about the implementation of the Italian Renaissance style. The fact that the palace of Lux Ritter had just been built at that time on the opposite side of the river may have encouraged the desire to apply the representative style to the new town hall as well. The master craftsman, Anton Isenmann, from Prismel was hired in 1602 to carry out the work and he recruited workers directly from Milan (Reinle 1954). The façades were designed in the rustic style and the external shape and structure were also inspired by Italian originals, but the shape of the roof rather corresponds to farmhouses and may not really fit the palazzo style, which was a reason for discussions during the construction period. However, on the first floor, a hall-like functional room, called Kornschütte, is located. The flat, wooden ceiling of the hall is supported by arcades resting on massive pillars and two supportive horizontal beams on columns. All elements consist of gray sandstone. Compared to the palace of Lux Ritter, which was built at about the same time in the same style and with the same basic material, completely different traces can be seen on the surfaces of the pillars.

4.2 *The pillars of the Kornschütte from 1602–04*

The pillars consist of individual cuboids of different formats. The outer edges are chamfered, the approximately 2.5 cm-wide peripheral edges run at a slant into the surface (Figure 6, left side). They show traces of a small chisel, as seen before in the Franciscan

Figure 6. The pillar in the Kornschütte of the town hall in Lucerne show traces of a pointed chisel and a serrated tool. (author 2019).

Church. Again, isolated punctiform holes are caused by a pointed chisel from the previous working step (see marking in Figure 6). They are about 3 mm in diameter. The surfaces are covered by small punctiform punched holes. These were generated by the use of a serrated tool, probably a serrated stone hammer or chisel. Compared to the traces of the same tool category on harder limestone (section 5.2), the traces on the gray sandstone appear more blurred. Since these tools are known to be used for harder stone types, their use can be questioned here, especially given that the massive arcade pillars on the south side of the town hall, the river side, were worked with a wide chisel. Since the elements are built at the same time and are both made of sandstone, the question arises: why did the stonemasons work with different tools on the arcade pillars? A possible explanation can be found in the need for representation. While the exterior arcades are part of the representative façade design, those of the hall are usually not visible to visitors, as the space is not part of the public area of the town hall. Removing the material with a serrated tool was likely more efficient in terms of time.

5 SANDSTONE AND LIMESTONE IN SOLOTHURN

For the Solothurn buildings, primarily gray Jurassic limestone and yellowish Hauterive limestone were used (Blank & Hochstrasser 2008). Today, sandstone building material is rarely found and is mainly limited to sculptural elements and smaller construction tasks such as window jambs. Several window jambs are preserved from the 16th and 17th century and show Gothic or Renaissance style features. Some of them are made out of sandstone and some of limestone.

5.1 *The window jambs in sandstone*

Figure 7. The window jamb in Friedhofgasse No. 11 shows Gothic features and processing traces of a wide chisel. (author 2020).

The window jambs on the second floor of the house in Friedhofgasse No. 11 originate from the time of a reconstruction between 1520 and 1530 (Blank & Hochstrasser 2008). They show Gothic-style features, such as intersecting round bars and ornaments (Figure 7). The jambs are painted over with white paint, but the stone working is still visible and clearly shows the traces caused by a wide chisel. The narrow profile of the edges has been processed with a smaller chisel, which creates the characteristic parallel and stronger lines, as seen before. A stonemason's mark is also visible on the central bar. Due to the colored coating, the type of stone cannot be visually determined, but the processing with tools typical for softer stones, such as sandstone, as well as the fine elaboration of the ornaments indicate that the windows were made of sandstone. The delicate ornaments require different tools, for this purpose stonemasons and sculptors had various fine tools at their disposal, such as small chisels with curved or pointed ends or scraping irons (Völkle 2016).

The house in Goldgasse No. 8 (Figure 8) has been documented as a mill since 1303 and was converted into a municipal mint house in 1622 (Blank & Hochstrasser 2008). A four-part staggered window of sandstone with fillets of plain appearance, created during the renewal of the mill in 1562 (Blank & Hochstrasser 2008), has been preserved on the west façade.

Figure 8. a (left) and b (right). Solothurn, Goldgasse 8. On the left the window jamb from 1562, on the right the jamb with volutes from 1622, both made out of sandstone (author 2020).

The narrow profiles of the edges are structured by the horizontal lines of a small chisel while the remaining surfaces show slightly more irregular lines of a chisel running parallel to each other. The length of the lines is estimated to be about 3–5 cm; it is possible that the same chisel was used for the wider areas and the narrow, straight profiles, as long as the width of the cutting edge was not an obstacle for these areas. Further windows, also made of sandstone, have been preserved from the time of the reconstruction in 1622 and show, in contrast to the window jamb from 1562, features which are characteristic for the Renaissance style, such as round bars and volutes. Their surfaces, on the other hand, show the same traces of processing as the staggered window from 1562. In areas with curved surfaces the chisels were guided vertically. The round bars show only a slight surface structure, and they were probably additionally smoothed as a final work step.

5.2 *The portal and window jambs in limestone*

In the Judengasse, where a vigorous building activity for the 16th century is documented (Blank & Hochstrasser 2008), several Late-Gothic staggered windows are preserved. One of those is located at house No. 5. The individual stones of the window jambs are delimited by peripheral edges that were processed with a small chisel. The remaining surfaces show the processing by a serrated tool (Figure 9). There are several serrated tools which are particularly well suited to effectively process brittle limestone. The traces visible on the surface of the window jamb let us infer the use of a serrated stone hammer (*boucharde, Stockhammer*, Figure 2 No. 10) a serrated chisel (*gradine, Gradiereisen*, Figure 2 No. 7) or a bush hammer (*peigne, Krönel*, Figure 2 No. 11).

Since the stonemason hits the surface several times with the serrated tool, the traces are usually not clearly assigned to a specific type. On surfaces that are not heavily eroded, it is sometimes possible to isolate traces with a linear or rectangular shape, which can indicate which tool was used. Since the concavely curved surfaces of this window soffit (see marking in Figure 9) also show uniform depths of the holes, a small serrated hammer with a convexly curved impact surface could have been used here. That a serrated hammer was also used for the window jambs can be assumed, but not proven.

Figure 9. Solothurn, window with concavely curved soffits in Judengasse 5, 16th century. (author 2020).

Figure 10. Window jamb in Friedhofsplatz 14, mid-17th century. (author 2020).

The tavern at Friedhofsplatz No. 14 results from the merging of several buildings over time, seen in the irregular window axes. On the southern façade, staggered windows made of gray limestone have been preserved from the 17th century (Blank & Hochstrasser 2008). The edges are worked with a small chisel, while the jambs and concavely curved soffits show traces of a serrated tool (Figure 10), just like those seen in Judengasse 5.

In 1681, two previous buildings had to be demolished to build the representative residential house in Schmiedengasse No. 1 (Blank & Hochstrasser

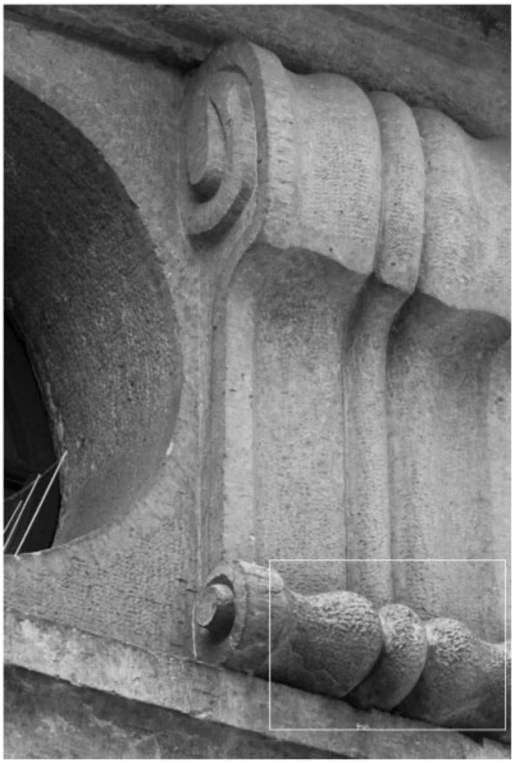

Figure 11. Solothurn, portal in Schmiedengasse 11, 1682. (author 2020).

2008). It shows the appropriate dimensions for a patrician building and a representative portal from 1682 (Blank & Hochstrasser 2008). With regard to the construction task, portal jambs differ only slightly from window jambs, for this reason this suitable example should be mentioned.

It is located on the east façade and is made of limestone. The consoles with volutes support the segment pediment and provide Renaissance-style features (Figure 11). The surface of the stone shows again the characteristic traces of a serrated tool. Profiled edges are again worked with a small chisel; they show the typical regular sequence of lines. The spiral-shaped areas of the volutes have also been worked with a narrow chisel; the use of a serrated stone hammer, even if it were delicately formed, would not be suitable for processing this type of surface. However, a serrated tool with a quite slender design was probably used for the curved surfaces of the volutes (see marking in Figure10). As with the findings on some curved window soffits made of limestone, it becomes evident that for such areas serrated tools with slimmer and curved cutting edges were probably used.

6 CONCLUSION

The investigation shows that the stylistic appearance of a building and its stone processing are subject to rather different considerations and should be evaluated independently. The findings in Lucerne and Solothurn from the 16th and 17th century show that the tools used were directly dependent on the material which required differentiated processing techniques.

If a stonemason was to use a wide chisel for working large surfaces of limestone, the cutting edge of the tool would wear out quite quickly and the whole blade would have to be frequently sharpened or exchanged. However, this tool is only conditionally suitable for removing the harder material and smoothing the surface. Therefore, the traces of a chisel on limestone are mostly found only on narrow profiles, where the processing is similar to elements made out of sandstone. A great advantage of both the serrated stone hammer and the bush hammer is that the spikes are individually replaceable, so single spikes can be easily exchanged. This makes them particularly suitable for processing the hard and brittle material found in Solothurn. Another aspect that can influence a stonemason’s choice of a specific tool is apparently the representative character. The surface texture can be used as a conscious finishing or, as in the palace of Lux Ritter, as a means of hierarchization. Among the examples studied, the town hall of Lucerne seems to be an interesting phenomenon. Although some serrated tools may be suitable for working softer stone, they were rather seldomly used for processing soft sandstone. One reason why the pillars in the hall of the town hall were processed with a rather unusual tool for this purpose could be its use as a purely functional room without a special representative claim. It is likely that the use of the serrated tool saved time and, thus, also costs.

In conclusion, the choice of the tool does not seem to depend on a particular architectural style, but on the material itself, on design requirements and on economic reasons. It made no difference whether a stonemason worked on a Renaissance portal or a Late-Gothic arcade pillar, he always used the appropriate tool for each stone.

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History of Construction Cultures – Mascarenhas-Mateus & Paula Pires (eds)

Stability and construction of the 16th century Mexican rubble masonry vaults in Jiutepec Morelos

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ABSTRACT: 16th century vault construction in convents in Mexico has rarely been studied from a technical standpoint. In fact, the preservation of such cultural heritage has been endangered due to poorly implemented interventions, lack of maintenance and a mostly inadequate understanding of the building's construction history and structural behavior. Furthermore, the field of the history of art studies has focused almost exclusively on describing the orders and styles of these buildings. The present paper goes beyond a mere description of these structures, aiming at their architectural survey and the application of limit analysis to understand their behaviors and construction processes.

1 INTRODUCTION AND RESEARCH SCOPE

During the 16th century, after the foundation of New Spain, the hegemonic Spanish empire imposed a certain architectural language over the conquered territory. After choosing a site with a wide and open space called the atrium, friars in the mendicant orders erected the first building, an open chapel where the friars were to convert the indigenous population. Consequently, the priority was to build the convent where they would live, generally consisting of a group of dependencies arranged around a cloister with an arcaded corridor. This was the general scheme for the far and wide territories of New Spain (Artigas 1985). The abundant indigenous workforce available made the erection of a great number of convents possible in a very short period, using their own construction techniques and materials in a new geometric system. The improvements in stone workmanship made by metal tools did not change their construction process completely, especially in the first stages of construction. The first vaults in New Spain were probably those used to cover the cloister corridors and dependencies. The first cloister arcades contained very broad columns that resembled walls with openings. These were made out of rough materials without precise stereotomy, constructed with centering (Kubler 1948). It was not until the second third of the 16th century that convent cloister arcades appeared, built in slender proportions and carefully carved blocks.

The ex-convent of Santiago Apóstol in Jiutepec, in what is now known as Morelos state, is located in central Mexico. Despite its convulsive history, it has survived to our days. The study of this building fosters an understanding of the premises the builders used to construct such vaults and explains why some of them are still standing while others are not. The earliest recording of this Franciscan convent in Jiutepec comes from the commissary-general Father Ponce, who in the 16th century travelled from convent to convent in New Spain with his secretary Antonio de Ciudad Real. In January 1586, they described this convent as follows: "estuvo acabado, hecho todo de bóveda, que no le faltaba más que la iglesia, y con un temblor grande de la tierra se cayò la mayor parte dèl, lo demàs quedò abierto como una granada; aderezàronse tres o cuatro celdas, en que moran los religiosos, que de ordinario son dos" (Ciudad Real 1976) (The convent was finished, all made in vaulting. Only the church was missing, and after one great tremor of the earth most of it did collapse. The rest was left open like a pomegranate. Three or four cells where the friars dwelled, generally about two, were appended). With the information hereby provided, we may assume the convent had been constructed without a temple. It was only partially reconstructed after the earthquake as Father Antonio happened to sojourn there. Other records of this convent date back to the 17th century, referenced a visit to the convent at Cuernavaca. The Jiutepec convent was of secondary importance compared to the other convents, it did not attract as much attention or resources as Cuernavaca. Nevertheless, it was one of the first buildings erected in this region.

Concerning the origins of vaulted constructions in Mexico, the first known barrel vaults appear in convent buildings, as is the case of Jiutepec. Although the mendicant orders had different criteria regarding their building requirements, the friars looked for quick and enduring solutions. Vaults were a primary construction goal for most of them. Although wooden roofs were widely used, many were gradually substituted by

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vaults to prevent fires or even after such incidents. Such vaults were built in places that did not previously have any.

The primary feature of vaults is their inherent thrust, which must be contained by walls or buttresses. Vaults were built using rules of proportion, a geometric system implemented by the Spanish in the 16th century. Understanding the methods, the friars used to determine the proportions of convent walls could lead to unravelling the history of vaults. In order to comprehend the possible dimensioning system applied, we may consult the renowned 17th century Spanish manuscript by Simón García. He wrote down many geometric rules and plans used by the 16th century architect and experienced builder Gil de Hontañón, who combined Renaissance and Medieval knowledge (Huerta 2002). One of the manuscripts (15r) depicts the proportion of a buttress or wall as a function of any genre of arch it must support. There is a splendid drawing accompanied with the description: "Esta demostraçion sirbe para saber lo que le toca de estribo a cualquiera genero de arco" (García 1681) "This proof serves the purpose of determining what the support of any type of arch should be" (author's translation), depending on its height and span. This simple geometric tool serves to verify the existing proportions in the Santiago Apostol convent. Carrying out this procedure does not necessarily imply that the same rule was used but does infer that the leading constructors in New Spain knew these rules of proportion. The study of these proportions is essential as is now known (Huerta 2004). Geometric proportions convey enough security for masonry buildings to this day. This assumption can be validated through limit analysis, demonstrating that the thrust line is completely inside the fabric (Heyman 1966). The range of safety of the walls can also be determined through limit analysis. The abutment safety is the most delicate in terms of equilibrium as the vault's stability depends directly on this factor.

2 THE CONVENT OF SANTIAGO APOSTOL: GEOMETRY AND STABILITY

This section provides an in-depth description of the geometric and constructive features of the convent discussed in the paper. The plans and sections in the following are the combined results of a survey made in 2018 with a Leica DISTO S910 and photogrammetry with an EO5 Canon camera, processed in the Agistoft PhotoScan program generating a point cloud, after which the point cloud was translated into CAD 2D and 3D drawings. The surveys conducted reveal that the lower cloister corridors at the ground floor (Figure 1) do not exhibit significant alterations in shape. On the contrary, the upper cloister plan (Figure 2) shows large amounts of damage, due to the collapse of walls and arcades as well as most of its roofing. Further studies on the geometry, particularly concerning the identification of its basic proportion, have been carried out by analyzing three main sections of the convent, named in the paper Section A-A', B-B' and D-D' and the upper cloister section C-C'.

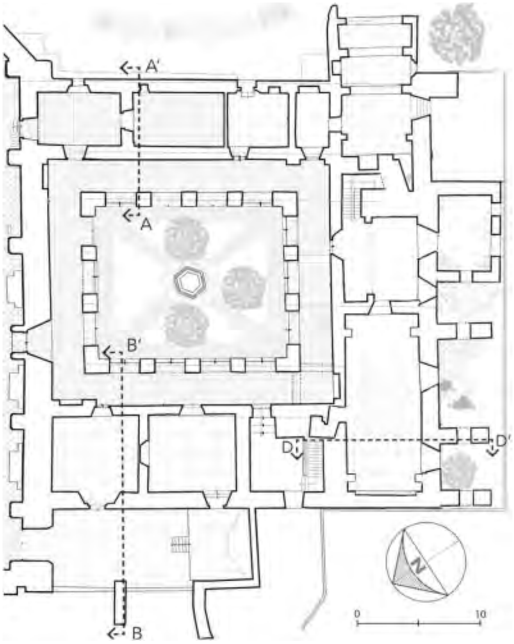

Figure 1. Plan of the Santiago Apóstol Lower Cloister.

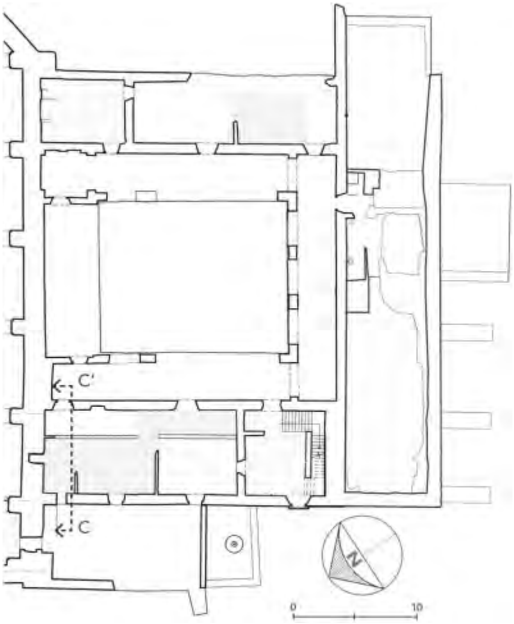

Figure 2. Plan of the Santiago Apostol Upper Cloister.

In addition, visual inspections have been performed on each construction element of the structure through which it was possible to identify the preponderant elements that constitute the convent's masonry.

Jiutepec stands in the neo volcanic axis, a region which supplied large quantities of volcanic rock, particularly volcanic scoria banks. A great variety of volcanic scoria is known as *Tezontle*. 18th century builders in New Spain, as described in the manuscript “Architectura mechanica”, called this rock a “divine material” (Cortés 2019). Tezontle is a very light porous rock, and it has been the primary construction material for monumental buildings in this region since Pre-Hispanic times, along with earthen constructions. It was used as a rock covering in monumental buildings with a lime mortar-based coating that was finished in a thin layer of lime-based paint.

The walls of the convent are made with tezontle rubble masonry carelessly arranged with large volumes of lime mortar packed in to absorb irregularities. By analyzing the mortar employed some of its components were identified. The presence of lime nodules indicates the mortar was applied in a semi-slake lime state. The clay and lime mortar with tezontle-sand confirms that both binders continued to be used throughout the region since Pre-Hispanic times. Moreover, this traditional technology was combined with Spanish construction techniques (Ledesma 2011). The available resources in the region had been used for construction by the locals throughout centuries. Deploying this knowledge, they continued to do what the Spanish imposed upon them. Additional research is required to characterize the mortar and the precise proportion of its components. The *plate bande* arches in the walls are made of limestone voussoirs, especially in the inner lower cloister corridor. In these cases, the jambs are made in the same way. In other cases, there are very few windows and with doorways defined by flat tezontle arches.

2.1 *Southeast dependencies*

2.1.1 *Lower cloister*

The southeast dependencies constitute one of the best-conserved zones of the lower cloister. They form part of the sacristy with direct access to the cloister corridors and the temple. Analysis of the geometry of section A-A’ determines that the cloister corridor and sacristy have segmented barrel vaults close to semicircular versions. Following the fourth rule of Gil de Hontañon (Huerta 2004) verifies that the outer wall has a correct proportion to support the vault, as shown in Figure 3. This was also proven for the inner arcade, which behaves like an abutment for the barrel vault of the cloister corridor. Even though the rules of Gil de Hontañon usually refer to arches, it has been confirmed that the same dimensional principles exposed above apply to vaults by analyzing their sections. These proportions are also independent of the building’s scale.

To verify the proportions of the structure, the principles of limit analysis can be used as described by Heyman for masonry structures. Structural analysis has been performed graphically by drawing the thrust-line, which illustrates the path of the compressive forces within the masonry. According to the *safe theorem*, the structure is safe if the line of thrust lies within its thickness (Heyman 1966; Huerta 2004). Other authors have discussed this topic and presented structural analyses of ancient masonry construction by using graphic statics applied to arches (Cennamo & Cusano 2018) and domes (Cennamo & Cusano 2018).

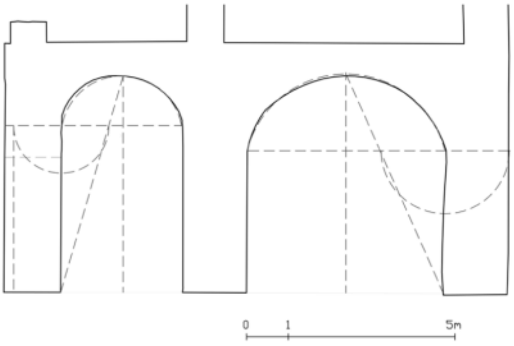

Figure 3. Lower Cloister Section A-A’ applying Gil de Hontañon’s fourth rule.

To assess the stability of the building, we consider here section A-A’, subdividing the vaults in voussoirs defined by the center of the vault’s directrix. These divisions do not correspond to the individual masonry of the vault. Rather, they represent blocks of appropriate size and weight to easily determine the vault’s general behavior. Additionally, the filling is considered in vertical segments. This procedure was implemented by assuming a vault thickness of 55 cm. The walls have also been divided into blocks, and considering a longitude of 6 m for every section. This also included calculating the volume, weight and centroid of each block. All this information is necessary to drafting the force polygon, which is drawn by considering the structure subjected exclusively to its own weight to assess the trajectory of the thrust line within the masonry. The graphic statics standard procedure above was described in 1982 by Heyman, outlining the process of finding a thrust line within the masonry of arches.

Figure 4 below shows the A-A’ section with the minimal thrust line analysis and the reconstructed geometry of the upper cloister corridor arcade with its inclined wooden and tiled roofing as well as the adjacent horizontal concrete slab roofing.

Once this is completed and the thrust line is obtained, the results suggest that the base of the wall is the most critical section. Assessing this claim involves determining the geometrical security coefficient of the abutment. Huerta understood this coefficient in terms of the position of the thrust line passing through the masonry at the base of the outer wall. The security of any section of a buttress depends on the eccentricity of the thrust line with respect to the center. This value is obtained by dividing the semidiameter over the eccentricity (Huerta 2004, 2010). This coefficient is equivalent to that defined by Heyman (1969) for arches. Applying this procedure to the base of the

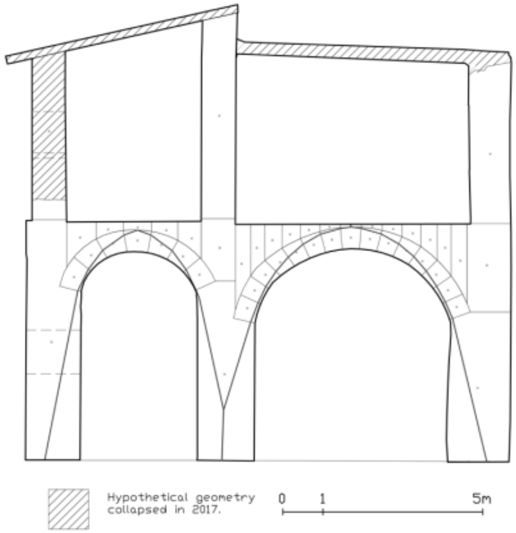

Figure 4. Complete Section A-A' according to the minimal thrust limit analysis.

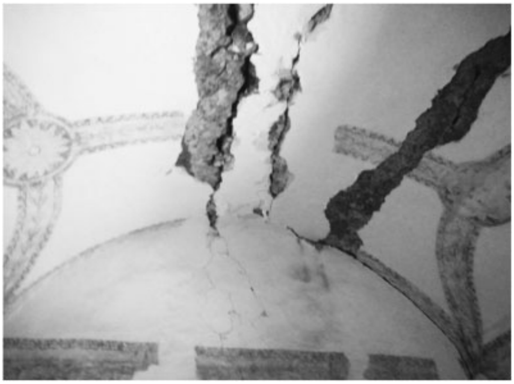

Figure 5. Sacristy, lower cloister from the intrados exposing longitudinal cracks, photo taken in 2017.

outer wall in section A-A', — which measures 1.53 m with an eccentricity of 0.21 m with respect to the minimal thrust line— will result in the division of 0.765 m (the semidiameter) over 0.21 m. In turn, this operation results in the value of 3.6 as the geometrical security coefficient. A security coefficient of 3 or more means that the thrust line is located within the middle third. This also identifies how there is a minor influence of the upper cloister wall on the lower cloister's vaults minimal thrust line. The same happens in the cloister arcade, which receives the thrust line in the middle third without the need for any load from the upper cloister arcade. This geometric security verifies that the filling is consistent, and the proportions are correct to supporting such a barrel vault.

The minimum thrust hypothesis (Heyman 1969) can be verified via the presence of longitudinal cracks visible in the crown region by the intrados, as shown in Figure 5, confirming the hinge mechanism assumed. It is not possible to see any groin cracks due to the filling, but the thrust line must be close to the minimal.

2.1.2 *Upper cloister*

The upper cloister was typically where the cells for the friars were located. The A-A' section in Figure 4 shows a clear difference with the lower cloister; the walls are slender and their span is larger. Therefore, to implement barrel vaults would be a risky roofing option at this level. The arguments above might suggest that such a level originally did not have any vaults. This hypothesis is also consistent with the southeast and southwest dependencies, which have no remains of vaulting, while the northeast dependencies had vaults until the earthquake of September 19, 2017. The remaining roof in the southeast dependencies consists of a concrete slab placed in the 20th century that mostly caused the out of plane rocking of the upper external wall in the earthquake. The upper cloister corridor never had vaults, its arcade is also slender with wooden roofing, which largely collapsed in the same earthquake.

2.2 *Northeast dependencies*

2.2.1 *Lower cloister*

The lower cloister is composed of three vaults. In the section B-B' in Figure 7, the outermost segmental vault covers what has been called the "open chapel", also seen from the façade of the convent building, with two arches and a buttress. Modified quite significantly in the 18th century, this even features a pair of lunettes in an upper section of the barrel vault that date to the construction of the current lunette vault in the temple. The second is a segmental vault between the open chapel and the cloister corridor. Both segmental vaults have a greater span than those in the southeast. The third barrel vault is that of the cloister corridor, displaying the same span as the other four sides with the same proportion of the arcade section as the abutment.

2.2.2 *Upper cloister*

The upper cloister is the only remaining witness of vaults in the whole level, the latter of which collapsed in 2017. Only a small portion of the vault remains attached to the southern temple wall. As the section C-C' in Figure 6 conveys, we may assume the same geometry was used to cover a larger portion of the upper cloister until it collapsed at some point. Studying its geometry by performing the thrust line analysis in the same way as described in the previous section demonstrates the structure exhibited an unstable arrangement resembling a collapse mechanism (Heyman 1966). This is due to insufficient abutments in both walls in relation to the span of this vault. The minimal thrust line, which follows the same procedure previously described, reveals that the geometric safety coefficient is at best equal to 1.6 in the base of the left wall (1.3 m thick) in section C-C in contrast to

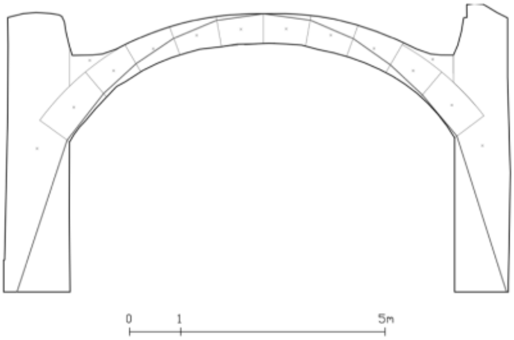

Figure 6. Section C-C' Isolating the upper cloister, minimal thrust line.

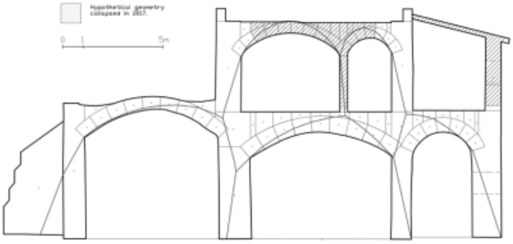

Figure 7. Section B-B' thrust line analysis on the reconstructed geometry, without considering the thin transverse walls.

the right side, which is clearly insufficient. This makes it very sensitive to any small variation in the forces or any overcharge applied to the structure. For this reason, it surely collapsed. The remaining portion of this vault adjacent to the temple in Figure 6 did not fail thanks to the containment provided by the stairs and an engrossment of the wall. Both elements worked as a buttress, considerably increasing the security of the vault for that limited portion.

Two vaults, one with a span resembling the lower cloister corridor vault, and another resembling a three-centered barrel vault with a shorter span occupied most of the northeast upper cloister, probably substituting the previous vault of section C-C'. To support both vaults a thin intermediate wall was also added. This solution was implemented at a lower height than the previous vault with greater filling covering the extrados up to the crown of the vaults. Both vaults collapsed in 2017 as seen in Figure 8. After reconstructing their hypothetical geometry, thrust line analysis was performed, as displayed in the section B-B' in Figure 7, that also reveals an unstable arrangement in the upper cloister, primarily due to the thin wall. By evaluating this vault configuration within the framework of limit analysis, we may assert that the increase in the filling did not contribute enough security to both vaults, and only partially improved the safety of the two external walls. Furthermore, the addition of the intermediate thin wall represented an asymmetrical loading to the lower vault, considerably altering the equilibrium of the lower cloister. The inadequate abutment of the slender upper cloister wall, when suffering an overload, altered its delicate stability, leading the two vaults and the wall to collapse.

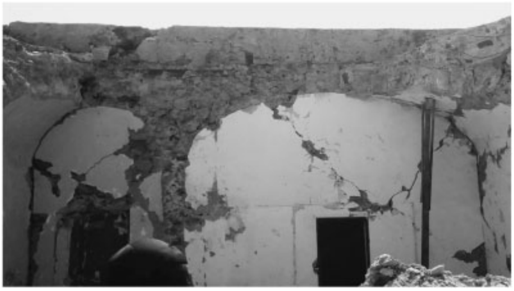

Figure 8. Upper cloister, remains of both vaults. Photo taken in 2017.

The reason why builders considered such a risky configuration of roofing for the upper cloister is unknown. They did not follow the geometric rules for vaults generally in effect at the time in contrast with the generally well-proportioned lower cloister. The reason that best explains this phenomenon is that the upper cloister corresponds to subsequent construction periods. It also corresponds to the introduction of baked clay bricks to define elements such as moldings and arches even within the tezontle wall masonry. The upper cloister arcade was formed by three centered arches made of these bricks in contrast to the very broad tezontle semi-circular arches in the lower cloister arcade. Figure 8 portrays the remains of both vaults in the upper cloister.

2.3 *Southwest dependencies*

This area is where the ancient refectory was located, also known as "the stables" in the 20th century. It has been in a state of abandonment for a long, indeterminate period. It was covered by a barrel vault that mostly collapsed, possibly in as early as the 16th century, before afterwards being partially reconstructed and reinforced by constructing buttresses in the outer wall. In the 18th century, a pair of segmented arches supported by pillars were also added. Despite this support, the outer wall yielded to the vault's thrust and caused its collapse or at least that is the leading hypothesis.

As seen in Figure 9, the remains of the vault display their constructive system. With a thickness of approximately 60 cm, the vault is made by elongated tezontle stones that match the description in "architectura mechanica", imperfectly cut like a long cornet that on the extrados looks almost like a porcupine, interlocked with more tezontle and mortar (Cortés 2019). Their springing is still intact, with rubble masonry filling placed carelessly in the groins. This construction system shows that wooden falsework was eeded for their making.

The segmented arch directrix of the vault can be discerned in the wall as seen in Figure 9, displaying a

Figure 9. Lower cloister, the stables, photo taken in 2018.

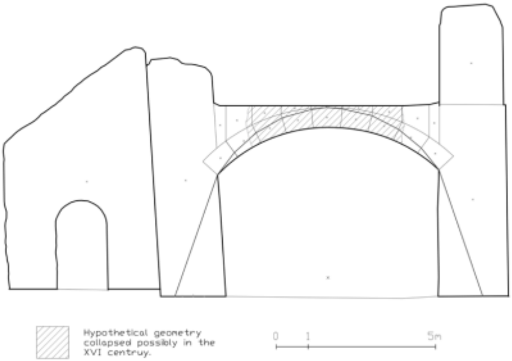

Figure 10. Section D-D' Minimal thrust line analysis.

greater span than that of the southeast and resembling the segmented vaults of the northeast. The upper cloister walls have also partially collapsed. It is not possible to visually define what its roofing was due to the lack of any evidence.

As seen in Figure 10 with the help of graphic statics applied to the reconstructed hypothetical geometry in the D-D' section, the minimal thrust line has been drawn through the vault. Despite the thickness of the outer wall (2.2 m), the geometric security coefficient at the base of the wall only reaches 1.77. Nevertheless, if the upper cloister had been covered with vaults, the wall's security coefficient might have diminished; whereas if it had a wooden roof, the weight of the upper cloister wall would have improved the 1.77 value. Furthermore, any security coefficient of less than two might mean differential settlements in the foundations, causing an overall inclination of the wall (Huerta 2004). However, the addition of the buttress greatly increases its security coefficient. After the analysis above, it is possible to deduce that the wall's proportion was not the sole cause for the vault collapsing. Indeed, the outer wall has a considerable outward inclination of 6%. Additional soil mechanics studies would be required to evaluate the particular soil conditions.

3 CONCLUSIONS

The use of barrel vaults implies the need for sizable buttresses or wall proportions in order to distribute the forces continuously and evenly. For different kinds of vaults, such as ribbed constructions, slender abutments are justified; as Gil de Hontañon reveals for pointed arches. Even so, the simpler geometric control of a single circumference during construction made segmental barrel vaults the most widely used in convent buildings in New Spain, especially in central Mexico during the 16th century.

After a careful survey, the geometry of the Santiago Apostol ex-convent vaults was reconstructed by representing it in two-dimensional drawings that permitted the application of graphic statics. The thrust-lines obtained have shown how rubble masonry vaults with the correct geometric proportions and enough abutment have endured and withstood diverse solicitations with different load configurations over time. In contrast, the rubble masonry vaults that lacked sufficient abutment and with riskier layouts collapsed or mostly disappeared when a sudden change in its loading occurred, especially during earthquakes. Following this analysis, we may assert that the material was not the problem. Even the rough stereotomy that constitutes the vault has virtually no influence on the general safety of the building which depends almost exclusively on its shape and geometric proportions. The stability of masonry constructions is a matter of geometry and does not depend on the lack of material resistance.

Visual inspection of the materials and study of the proportions of each constructive element confirms that the upper cloister corresponds to other construction periods, reconstructed at some point between the 17th and 18th centuries. The lack of continuity in building knowledge is evidenced from the first friars to the master builders. This was possibly due to the scarcity of master builders and the questionable expertise of some. These two factors could have caused poor design decisions like the use of barrel vaults in the upper cloister over slender walls. The former decision had severe consequences for the structure. In fact, progressive construction, described as "adding one or two cells for the friars", contributed to the lack of a global scheme of correct geometric proportions to receive consistent roofing throughout the upper cloister. Furthermore, the alterations of the building in the 20th century took its toll on the already delicate and misused structure as slab roofing proved to be a poor choice as demonstrated by the earthquake of September 19, 2017.

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History of Construction Cultures – Mascarenhas-Mateus & Paula Pires (eds)

The construction of the vaults in the cathedrals of the Viceroyalty of Peru

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ABSTRACT: In the Viceroyalty of Peru, political power was strongly linked to religion. In the first hundred years following the Spanish Conquest, the magnificent cathedrals, symbolically representing the Spanish dominion, became the reference construction model with the introduction of vaulted masonry structures. Juan Miguel de Veramendi, Francisco Becerra, Francisco Domínguez Chávez y Orellana and other architects from the Old World designed the most important colonial churches. The masons who gave life to the European forms were native, thanks to their ancestral mastery of the building material. Since these areas were frequently affected by earthquakes, many churches have been completely transformed over the years. The evolution of these structures is examined through the analysis of the remaining vaults, the evaluation of scientific literature and a thorough archival review. More specifically, the Cathedrals of Lima and Cusco explain the different experiments undertaken to make vaulted structures resistant to earthquakes.

1 INTRODUCTION

When Pizarro entered Cusco, the ancient Inca capital, in 1533, he had completed the conquest of Peru (Del Busto 1994). The following year, on 23 March, the Spaniards founded a major Spanish city in Cusco, at this time the most important colonial city in South America. Pizarro, appointed governor of the lands conquered by the Spanish Crown, founded another city on the coast of the Pacific Ocean in 1535. Lima, formerly known as *Ciudad de los Reyes*, gained prestige after being designated as the new capital of the Viceroyalty of Peru and site of a Real Audiencia (royal court) in 1543 (Hemming 1970). In Colonial Latin America, political power was strongly linked to religion, as only the need to convert natives to the Christian faith could morally justify their submission. Therefore, the construction of magnificent Christian temples with their symbolic meaning, replacing the first temporary Spanish buildings, became the opportunity for a cultural and architectural knowledge transfer from the Motherland to the New World. Between the last decades of the 16th century and the middle of the 17th century, Iberians architects were consulted or appointed to design the most important colonial churches or new cathedrals (Dorta 1960). For the purpose of this paper, a brief overview on the political context is provided only with the aim to present the findings of the research, while keeping a strictly defined perspective on the history of building technology.

2 HISTORICAL BACKGROUND

The first bishopric in the Viceroyalty of Peru, the Diocese of Cusco, was established on 5 September 1536 and stretched over a vast majority of the South American territory divided by the Archdiocese of Seville. Lima was raised into a bishopric in 1541, and subsequently decreed Metropolitan Archdiocese by Pope Paul III in 1546. In the following years, the diocesan territory of Cusco was further divided with the creation of the Bishopric of Paraguay, founded by Pope Paul III in 1547, and the Dioceses of Chuquisaca – Sucre – in Upper Peru, was founded by Pope Julius III in 1552. Shortly after the settlement of the *Conquistadores*, a small religious building was built in Cusco with adobe walls and lowly architectural features. In 1543, Jerónimo de Loayza, the first archbishop of Lima (1498–1575), signed the act of erection of the Cathedral of Lima while he was still in Madrid (Coello 2011). The possibility of being assigned the construction of remarkable churches outside of Spain quickly encouraged architects and master builders to cross the Atlantic Ocean. It is worth noting that late medieval and early modern Spanish architectural history must be considered to properly understand the sources of the early colonial architecture, as well as the local American context (Niell & Sundt 2015). Since Peru and surrounding areas were frequently affected by earthquakes, many churches have been totally transformed over time.

3 THE CONSTRUCTION OF THE VAULTS

3.1 *Early American religious architecture*

The evolution of building techniques in the Viceroyalty of Peru is examined through the analysis of the still existing vaults in the main churches, a scientific literature and archival review – the last of these including

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historical drawings or pictures, written documents, and photos.

Due to the long construction times, most of the early colonial churches show a range of architectural styles and building processes. As an example, the investigation on the Lima and Cusco cathedrals, as well as on some other South American architectures, shows the various processes used to make the vaulted structures resistant to earthquakes (Rodríguez-Camilloni 2006).

The early Latin American cathedrals were mainly single-nave churches with a simple wooden roof. European builders introduced solutions for the construction of masonry vaults over the monumental spaces of the news church naves and chapels. With the instruction of these architects, Gothic rib vaulting was introduced in Peru in the mid-16th century.

Stone vaults lent an air of solemnity to the sacred space while also conveying a sense of permanence to the Spanish occupation. Gothic architecture carried many ideological messages tied to the economic, politics and cultural development of ancient, medieval, and early modern Spain that helped in the colonization project. Shortly after, Renaissance and Baroque were added to the late medieval forms, such as barrel and domical vaults (Niell & Sundt 2015).

In Peru during this period, traditional and new, indigenous and imported artistic shapes engendered a visual heterogeneity (Brown 1991).

The inexperience of master builders was among the main challenges in spreading the European building technologies, alongside issues of the availability of building materials and training of a native workforce who was not familiar with European construction techniques (Niell & Sundt 2015).

Juan Miguel de Veramendi, from Biscay (early 16th century-1573) and Francisco Becerra, born in Trujillo, Extremadura (1545–1605) were among the most remarkable architects who came from Spain to the Viceroyalty of Peru in the second half of the 16th century. Their professional training, with a Gothic-Mannerist background, characterized the early colonial architecture (Dorta 1943). Both contributed to the dissemination of building techniques from their homeland to the main cities of America.

Veramendi planned the Cathedral of Sucre in 1551. In the same period, he was also commissioned the design of a new cathedral in Cusco, replacing the former adobe building. Approximately 10 years later, both the construction of Sucre and building works in the ancient capital of the Inca empire were stopped (Ugarte 1968).

3.2 *The mother churches of Cusco and Lima*

After the conquest of Cusco, the Spanish decided to take down one of the ancient temples of the Inca capital, replacing it with a Christian church in the main square of the city. Shortly after, Pizarro laid in Lima the first stone of the early church in 1535. The first cathedral in the colonial capital was also small and poor. This new temple in Lima was completed in 1538. A few years later, these first religious buildings had to be replaced with new churches that were bigger and more resistant, statelier and more representative, but still built with adobe walls and wooden roofs (Dorta 1960). In Cusco, the construction site of the new cathedral was settled in 1552. The architect Veramendi set up the foundations using large stones removed from some ancient Inca buildings, mostly from the fortress of Sacsayhuaman (Esquivel & Navia 1980). Veramendi's design is unknown, but the plan corresponded to the established foundations: a Latin cross, with various aisled naves. The roof had to be supported by 14 pillars (Flores 2013). Contemporary evidence suggests that Veramendi planned a vaulted stone ceiling for all naves, probably with more classical than Gothic features (Esquivel & Navia 1980). Back then, the indigenous people were highly skilled in building stonework, but had never erected arches and vaults. Most of the material was carried from Sacsayhuaman to the construction site of Cusco Cathedral in 1559.

The stone foundations of the church were laid in the following year (Flores 2013; Gutiérrez 2000). In 1561, the construction of the church of Sucre was interrupted due to serious technical problems. For this reason, the bishopric of Chuquisaca initiated a trial against Becerra, who could not leave the city in Upper Peru for 20 years and was unable to go to Cusco where construction had just started. In Cusco, Veramendi was replaced by Juan Correa as master builder of the cathedral from 1 September 1561 until 1564.

However, a lack of economic resources stopped the works. Although Francisco Toledo, shortly after becoming Viceroy of Peru, financed the construction of Cusco, the erection of the Cathedral proceeded very slowly above the foundations level (Dorta 1943; Flores 2013). In 1564 Jerónimo de Loayza, the Archbishop of Lima, commissioned the reconstruction of the Cathedral to Alonso Beltrán, with instructions to set up his design with five naves, just like the Cathedral of Seville, in Spain.

The building of Seville was the main church of the Archdiocese on which the New World initially depended. In Lima, the reconstruction of the Cathedral began in 1572 with the demolition of the existing adobe walls. In the capital of the Viceroyalty of Peru, the construction of the new main church was quickly interrupted because of the high cost (Mazzanti 2020). When Viceroy Toledo's government came to an end in 1581, he was succeeded by the 6th Viceroy of Peru, Martín Enríquez de Almansa, a new promoter of the cathedral works in Lima and Cusco (Figure 1). Martín met Francisco Becerra in Mexico and requested his presence also in South America (Harth-Terré 1945).

3.3 *Becerra's designs for Cusco and Lima*

Becerra's presence at the construction site of the Cathedral of Cusco is still under investigation; he almost surely made some changes to the original plan in 1581 (Flores 2013). Three years later, the architect revised the design again: in this new phase the church was planned with five naves, similarly to the mother church of Seville (Covarrubias Pozo 1958).

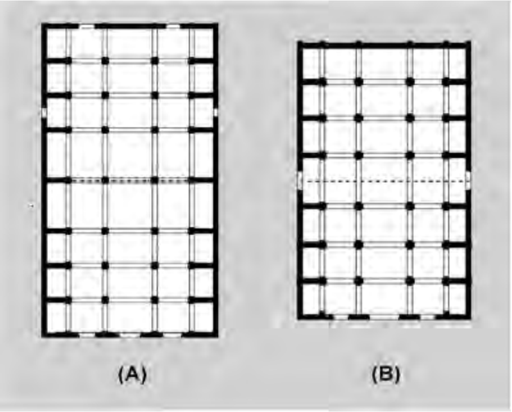

Figure 1. Schemes of the plans of the cathedrals with three naves and lateral chapels, designed by Francisco Becerra in the Viceroyalty of Peru: A) Lima; B) Cusco.

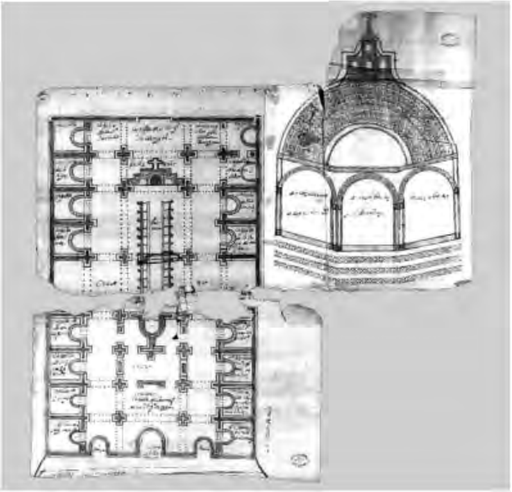

Figure 2. Cathedral of Cusco. Plan after Becerra's death, early 17th century (Flores 2013).

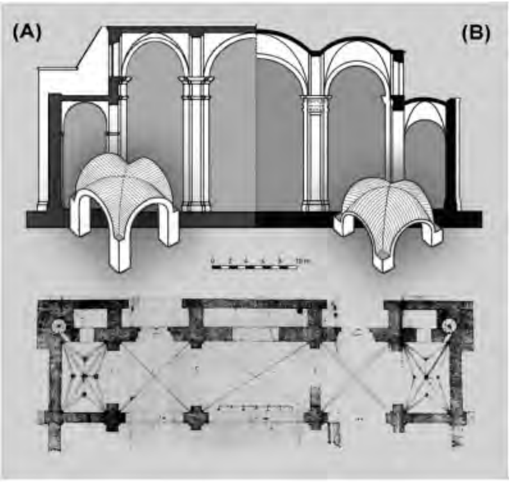

Figure 3. Cathedral of Lima. In the upper part: A) Becerra's design, the hypothetical section according to Rodríguez-Camilloni (2006); B) The building after Becerra's death, according to Flores (2013). Below: floor plan, Corral's proposal of 1609 (Archive of the Ecclesiastical Chapter, Lima).

Becerra's buildings were similar to some Spanish churches, especially in Andalusia and Castile, as well as comparable to the models presented by the Spanish architectural treatises of the time. Luis de Velasco, Marquis of Salinas and 9th Viceroy of Peru as of 1596, also had to deal with the construction problem of Cusco Cathedral in 1598 (Flores 2013).

During those years, Andrés de Espinosa, the master builder – *alarife* – at the Cathedral of Lima was already preparing the centerings to build the ribbed vaults. However, he was replaced by the architect Becerra (Figure 2).

This change led to abandoning that already antiquated type of vaults, specific to the medieval period, and the subsequent adoption of groin vaults according to the Renaissance shape (San Cristóbal 1996). Nevertheless, Becerra did not direct the works of the Cathedral of Cusco and his presence in the city was only reported as a visitor. Indeed, his name did not appear in the registers of the time. But the design of the Cathedral of Lima is surely attributable to Becerra (Figure 3), being similar to the final configuration of the main church of Cusco.

Construction of the Cathedral in Lima continued following Becerra's plans, and on 2 February 1604, when the eastern end of the new church was consecrated, the first two bays of the central nave with the aisles and lateral chapels had been completed and the web or stone shell of the vault was laid on them (Montesinos 1906). The Lima earthquake of 1606 seriously damaged Becerra's Renaissance vaults. In the following three years, the works continued westward at a slow pace due to financial difficulties as well as Becerra's death. At least two additional bays, including the lateral chapels, were standing when the strongest earthquake of 1609 struck the city (Dorta 1960).

3.4 *The construction after Becerra in Lima*

After the earthquake, structural damage to the vaults was assessed by Luis de Palomares Vega, superintendent of the construction site Cathedral – the *obrero mayor.* Additionally, before the Real Audiencia he requested the calling of a council of experienced architects to define the most suitable repairs (Rodríguez-Camilloni 2006). The master builder Alonso de Morales was the first to give an opinion on the repairs. In his report, he stated that the collapsed vaults were located towards the eastern end. In addition, the larger chapels – or rather, the transept of the Cathedral according to the Becerra design – suffered considerable damage in the piers and arches (Rodríguez-Camilloni 2006). In the apse, Alonso de

Morales decided against the use of exterior buttresses to avoid making unsightly the space of the nearby cemetery, but also increasing the lack of longitudinal stiffness. Instead, he proposed a reduction in the height of the naves and the construction of chapels similar to the lateral ones so that they would work as strong buttresses, increasing the solidity of the whole structure. Also on the council of architects was the architect Juan del Corral, born in Burgos, Spain, in 1571. Corral was active in Quito as of 1601, where he had earned the prestigious title of *Maestro mayor de reales fábricas* (Harth-Terre 1945; Webster 2012). In the year before the 1609 earthquake, he moved from the north of the Viceroyalty of Peru to Lima, to build the city's Old Stone Bridge. Corral recognized the need for buttressing the apse of the church and submitted his report on 27 October 1609 (Dorta 1960; Harth-Terre 1945). His floor plan for the eastern end, an important historical testimony (Figure 3), is currently preserved in Lima, in the Archive of the Ecclesiastical Chapter (*Cabildo*) (Ballesteros 1972). Corral's proposal contained some advice, also included in the aforementioned plan, such as the use of Gothic rib vaults over the lateral chapels following the medieval tradition that was part of his training (Vargas 1972; Ugarte 1968).

For the nave and the aisles, Corral decided to keep the shape of the groin vaults without changing the Becerra setting, but he planned to use wood instead of brick. Even though his suggestion was rejected at the time, Corral predicted the definitive structural solution that was adopted more than a century later, after the great earthquake of 1746 (San Cristóbal 2011). The Jesuit Martín de Aizpitarte was another architect who endorsed the idea of using wood to cover the naves of the Cathedral (Ugarte 1968). As for the construction materials, he indicated that the poor quality of the mortar could be blamed in part for the structural failure of the piers and vaults (Rossi et al. 2019). At last, in 1614, the master builder Juan Martínez de Arrona presented a plan with a comprehensive solution for rebuilding the Cathedral. The new design was approved in February of the following year. The construction works culminated with the completion of the western half of the church in 1622 and its consecration in 1625 (Harth-Terre 1961). The main transformation of the Cathedral, compared to the Becerra's design, concerned the replacement of the groin vaults for Gothic rib vaults (Wethey 1949). Arrona's own preference would have been to rebuild the Renaissance vaults, *a la romana*, like his predecessor Becerra. However, as he conceded, experience showed that rib vaults were the most effective in the event of an earthquake (Figure 4). The thrust of the Gothic cross vault built by Becerra is less than half the thrust of a Renaissance barrel vault designed by Corral. Some structures with rib vaults had survived the violent shaking following the Lima earthquakes of 1609.

3.5 *The Cusco Cathedral after Becerra*

In the early 17th century, various events happened in Cusco – including Becerra's death, after which several architects modified the design of the Cathedral. Then, between 1615 and 1616, serious disagreements occurred between the construction workers in the city which halted the building process for nine years (Figure 5).

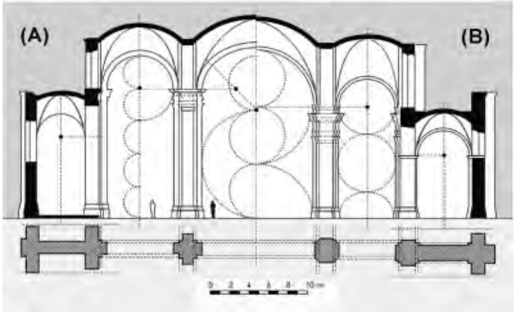

Figure 4. Sections of the cathedrals of Lima (A) and Cusco (B) at the beginning of the 17th century (in Flores 2013).

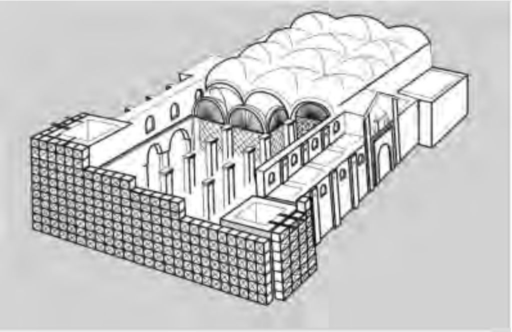

Figure 5. Cathedral of Cusco. Work in progress, at the time of the 1650 earthquake. The complete vaults in the area towards the altar (in Flores 2013).

The completed structure reached the level of the cornice at the top of pillars and walls. The layout was later modified by the master builder Gutiérrez Sencio in 1625 (Tesoros: 64). Nearly 20 years later, in 1643, the Spanish architect Francisco Domínguez Chávez y Orellana arrived in Cusco.

At the same time, Juan Alonso Ocón became Bishop of the city. Both the architect and the bishop made a vast contribution to the conclusion of the main church of Cusco. Meanwhile, Gutiérrez Sencio continued to direct the building site at the cathedral until his death in 1649.

The progress of the cathedral works had been accurately noted until then by the friars Juan Alonso Ocón and Juan de Córdoba. The latter, who was also Rector of the Society of Jesus in Cusco, wrote a report on the Cathedral in 1645. In this report, he gives us significant information about the walls, pillars, façade, and part of the towers. Above all, the most important testimony concerns the structure of the vaults (Flores 2013).

Figure 6. Cathedral of Cusco. The structure of a vault without the plaster, during the restoration works in 1997 (in Flores 2013).

Figure 7. Cathedral of Cusco. A cross vault in the aisle, bottom view, current state after restoration (in Flores 2013).

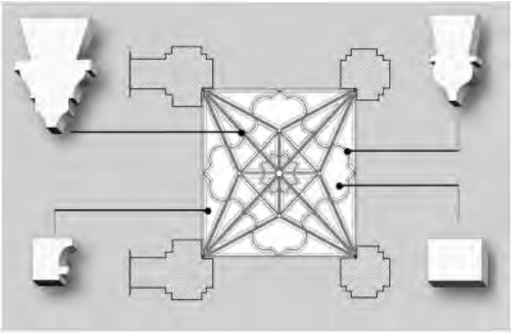

Figure 8. Cathedral of Cusco. Technical detail of a rib vault in the aisle: identification of the specially shaped bricks of the vault brick web.

Figure 9. Cathedral of Cusco. The "flat roof" and the extrados of the vaults (the slope of the surface in evidence).

In the same period, the early Santo Francisco church of Cusco was demolished in order to modernize its structures (Angles Vargas 1983). The aforementioned architect Chávez y Orellana was involved in 1648 in the construction of the cross vaults in the aisles, transept and presbytery (Flores 2013).

After his death, Gutiérrez Sencio was replaced by Chávez y Orellana, chosen only for his previous experience in the construction of San Francisco. On 16 August 1649 he signed a contract to build 17 brick rib vaults in the three naves of the Cusco Cathedral, from the facade to the choir, following a new design. Four experienced Spanish bricklayers worked under the architect's supervision. Their work would be completed in 40 months: each vault needed approximately a month and a half to be built, plus a whole year to carry out the finishes (Figures 6, 7 and 8).

Religious people and the population of the city supplied the construction with the economic resources needed and the available materials, typical of the Andean areas (Proaño et al. 2004), such as brick, lime, and roof trusses.

The extrados of the vaults was not covered by a wooden roof but by very thin, light bricks commonly called *ladrillo pastelero*, forming the slope of the surface (Figure 9). Waterproofing the flat roof was crucial, especially during the heavy rains typical of Cusco.

A similar example is the cathedral of Málaga in Andalusia, a region with very little atmospheric precipitation during the year, unlike Cusco. The 1650 earthquake destroyed the ancient Inca capital, but the unfinished roof structures of the Cathedral (Figure 5) were only slightly damaged, so the Spanish architect was able to complete the building in the following four years. The work was completed in 1654. On 21 May 1950, a new, violent earthquake struck Cusco, damaging a lot of buildings – especially the colonial churches, which were 250 to 350 years old, and the adobe constructions. But the Cathedral structure suffered only light damage, and only the façade and the two towers were affected. More specifically, some crenellations and the upper finials on the façade toppled over.

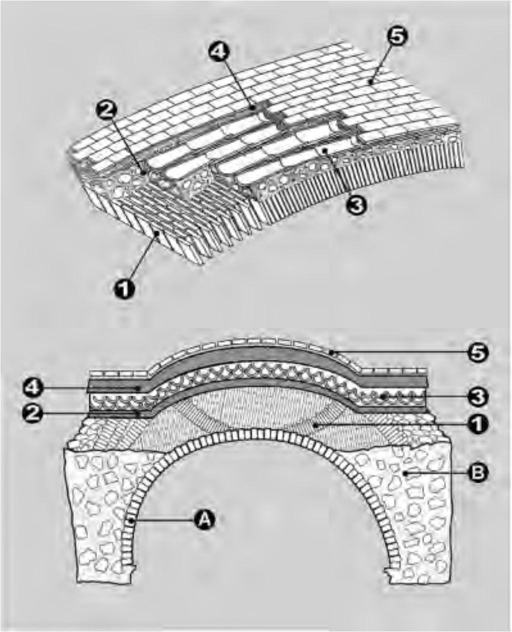

Figure 10. Cathedral of Cusco. Structure of the vaults: A) main arches; B) spandrel, conglomerate of stones and mortar; 1) web vault and ribs; 2) mortar conglomerate; 3) tiles; 4); mortar conglomerate; 5) bricks, *ladrillo pastelero.*

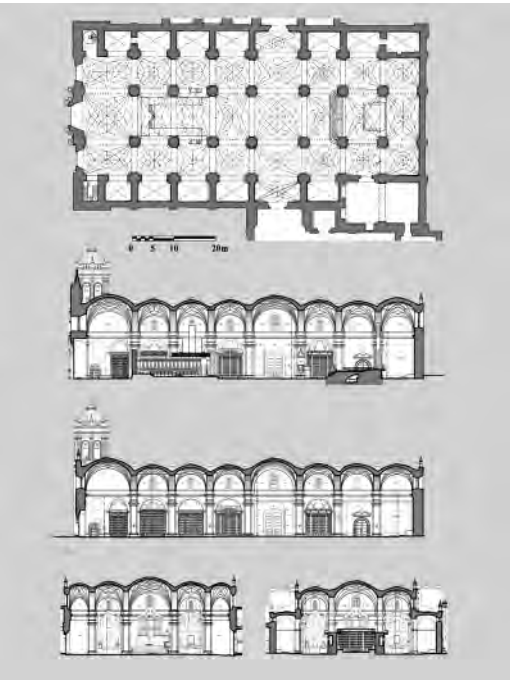

Figure 11. Cathedral of Cusco. Architectural survey: floor plan, longitudinal and transverse sections.

In the corner supports, the grinding action of the rubble fill within the rusticated facings was clearly evident. In contrast, in all the vaults of the naves, damage was negligible (Kubler 1953). In 1986, another, less devastating earthquake caused minor but significant damage in Cusco. Once again, the Cathedral vaults withstood the event. The vaults were repaired during the restoration of the building in 1997 (De La Serna & Carrillo 1996).

4 CONCLUSIONS

Following the destructive Lima earthquake in 1746, the brick rib vaults of the Cathedral were rebuilt in wood by the Scottish architect Alejandro Campobello between 1751 and 1758 (Harth-Terre 1951). Therefore, the most effective protective solution in the most important church of Lima was found in *quincha* construction (Rodriguez-Camilloni 2003). In the whole Viceroyalty of Peru, only the Cusco cathedral preserved the vaults built at the beginning of the 17th century. The analysis of the Gothic vaults (Figure 10) showed the technical features which made the entire structure resistant to earthquakes, as demonstrated by its response following the destructive event of 1950 (Brando et al. 2019). The presence of transverse ribs, liernes and tiercerons, with straight and curvilinear shapes, split the web of the vault into independent wall elements. Brick vaults were arranged in rowlock courses, following concentric rings, to build vaults with a minimum of temporary wooden centering.

The complex roof shape, with a very light double curvature masonry structure, increases the stability of the vaults. Beyond any stylistic consideration, rib vaulting was very popular among colonial architects because they believed that Gothic construction would show greater resistance to earthquakes.

Even for architects who had been trained in the classical tradition of the Renaissance, the adoption of rib vaults became a matter of structural expediency rather than a stylistic preference (Figures 11 and 12).

A broader knowledge of the construction history in the Viceroyalty of Peru allows us to understand the process with which the Viceregal builders of origin and training built an autonomous and specific architecture from the mid-17th century. A distinctive relationship with the materials characterizes the Andean, and particularly the Inca, approach to the built environment. The native bricklayers were deeply engaged with materials and with the processes that transformed those materials into structures (Webster 2011). Their active cooperation in the construction of the vaults in the main churches of ancient Peru allowed them to quickly learn this construction technique.

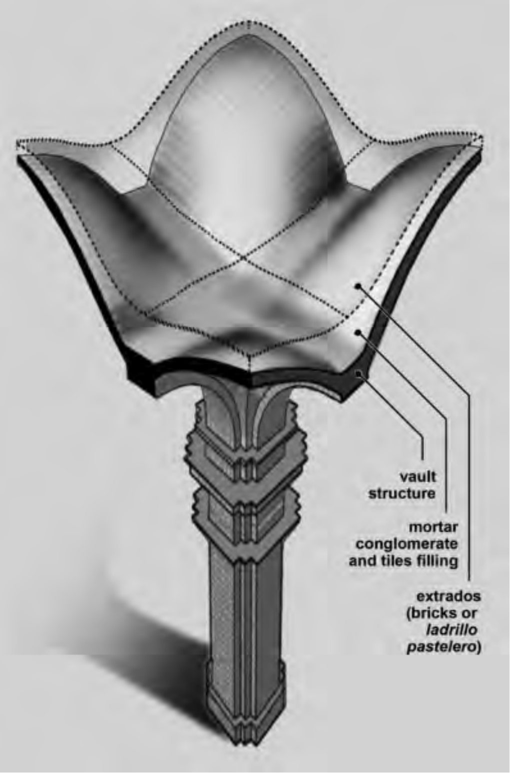

Figure 12. Cathedral of Cusco. Pillar and section of the vaults.

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Conception, materiality and development of coffered vaults in the churches of Goa

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ABSTRACT: A visitor to Old Goa could be surprised by the marked use of coffered vaults with specific characteristics which exist in many of the churches. However, they are a common feature throughout the region of Goa, a fact which has received very little attention in existing research. This article aims to contextualize the establishment of this architectural typology and its characteristics, to evaluate the advantages and disadvantages of its construction and understand how it survived the following centuries.

1 INTRODUCTION

Following Alfonso de Alburquerque's conquest in 1510, the city of Goa became an important Portuguese settlement. Thanks to its strategic location, Goa gained increased relevance until it became the capital of the *State of India* in 1530 and consequently the center of the Eastern Portuguese regions.

Often compared to Lisbon due to its economic and strategic activity, Goa had a further role in the post Thomasine Christian evangelization of the Indian new territories. Witness to this is its religious architecture. It was declared a UNESCO World Heritage Site in 1986 despite the loss of the urban environment in which it was conceived after the city's abandonment at the end of the 17th century.

The doctoral thesis that Nunes Pereira defended in 2003 is one of the most extensive and global works on the construction of churches in the period of maximum splendor of the city. Nevertheless, the descriptions given do not provide an in-depth monitoring of the evolution of the physical covering of spaces. This aspect should not be overlooked, since the repeated use of coffers is unusual at first glance.

Later works, such as the magnificent volume dedicated to Portuguese heritage in Asia and Oceania coordinated by José Mattoso in 2011, highlighted the splendor of the Old Goa constructions that influenced the way of conceiving churches in the rest of the region. We can say that this assertion is also valid in the case of coffered vaults.

A specific database of the churches in the region has been developed to reach this conclusion. These churches were found mainly in the *Virtual Museum of Images and Sounds* of the *American Institute of India* and in the pertinent bibliography (Lourenço 2011; Mattoso 2011: 171–334; Rodríguez Llera 2019: 193–9). Of the 64 churches built and reformed up to the 18th century and whose interiors could be evaluated, 39 of them have coffered vaults with different variations in the chancel. Occasionally and to a lesser extent, the presence of coffers has also been found in the nave or naves and in the lateral chapels where relevant.

A closed analysis is nowadays impossible, because of the transformations which have yet not been well studied and the disappearance of many rural churches. However, the evolution of the use of the coffers can be already perceived as a standard solution in Goan architecture.

2 BACKGROUND

The Franciscans arrived in Goa with the first Portuguese expeditions and had the monopoly on religious work in the region in a period when evangelization had not yet been conceived as a conquest strategy. The conversions were not very relevant during the first three decades and there was a certain tolerance of beliefs. Hindus were considered Christians who, unlike Muslims and Jews, only had to be indoctrinated correctly (Mendoça 2002: 34–5, 106–9).

Around the 1540s the renovation of the first temporary churches took place, built originally with palm roofs. With the exception of some representative churches, mostly in Old Goa, they opted for temples with one single nave built in stone with wooden roofs, a deep chancel in Portuguese style and occasionally attached lateral chapels. The chancel was typically framed by an arch with a considerably plain decoration compared with the exoticism that Manueline architecture presented (Figure 1). Externally the churches were marked by whitewashed facades, an aspect which is also transferred to the interior, mainly as a protection of the stone since this does not withstand the inclement weather well (Mattoso 2011: 180).

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Figure 1. Bom Gesú, Jesuit church in Old Goa. Prototype church with crossing trellis vault in the chancel.

The arrival of the Jesuit, San Francisco Javier, in 1542 as the highest representative of the newly founded religious order in Rome brought about changes in the conception of evangelization. The conversions increased and became a political objective because they helped to consolidate and defend the already conquered territory (Mendoça 2002: 109–13). This growth caused the separation of the diocese of Goa (founded in 1533) from Lisbon. A new archdiocese was established there in 1557 and all the territory between the Cape of Good Hope and Japan was dependent on it.

This new situation generated the necessity to build churches to respond to the growing spiritual demand. These spaces should inspire believers and above all, continue to encourage conversions, not least since the money that the Orders received from the government depended on the number of new parishioners.

The chapel of *Our Lady of the Rosary* in Old Goa, built between 1543 and 1549, is one of the best examples of this period, because it has been preserved almost intact due to its more remote location (Nunes Pereira 2003: 62–7). Reproducing the church layout as described above, the altar was covered here with a stellar vault. In contrast, as another witness of the same period, the chapel of *Our Lady of the Mount* already has coffered barrel vaults in the chancel and in the nave.

From our point of view, the change of style should not only be justified in this context by the search for renovation in architecture but rather by the consideration of technical issues. Gothic ribbed vaults were difficult to conceive unless the master-builder had carried out a long apprenticeship and several years of practice. In contrast, Renaissance rules based on Vitruvian fundamentals offered greater guarantees and were easier to understand (Harvey 1958). Undoubtedly this aspect should have been especially relevant in the Indo-Portuguese context.

3 THE FORMATION OF THE TYPOLOGY

The persistent use of coffers suggests that a rational and standardized model was chosen which could be easily elaborated and repeated. Although no specific references have been found at the moment for the construction of coffers in Goa, H. Carita presented a series of examples and contracts which allow us to verify that the normalization of requirements for the construction of some architectural elements was sought (Carita 2007).

An architectural typology which could be used for the development of church interiors should be remarkable and of course be representative enough to symbolize the Roman Catholic dogmas correctly.

Portugal had a pact with the Vatican, the so called "*padroado*", through which it was promised to expand Christian legacy in the new territories. In this context, the architecture could be a resource for this purpose: from the Council of Trent, taking place in those years (1545–63), art was recognized as one of the most effective propaganda tools.

The coffers, also called caissons, are a very forceful formal element that reinforces the perspective of the space. If they are used in the chancel, they also help direct the sight of the faithful to the altar and the altarpiece, where the devotional saints are located. This effect made it possible to seat the celebration of the Eucharist in the central focus of the place. With the repetition of the motif it would be easy for new believers to relate an ideal of architecture to the new way of religious life. This association was not necessary in Portugal, since Faith and Christianity were already rooted in the culture; nevertheless the use of coffers was understood as a symbol of renewal as in the rest of Europe.

The architects and artists of the Renaissance had rediscovered the coffers in Italy from the study of ancient Roman buildings such as the Pantheon and the Baths of Diocletian. Their use reappears timidly in paintings in the *Quattrocento* while in architecture this happened particularly since the planning and construction of St. Peter's Basilica in Rome. This building had an unquestionably great significance and served as an inspiration for many others in the subsequent years. The introduction of coffers in the formal Portuguese repertoire occurs through micro-architecture. However, it is first with the work of João de Ruão from the 1530s when it really begins to be used as a repeatable architectural resource (Lobo 2020).

The typology arrives in Goa after some notable buildings with coffered vaults could be already found in Portugal. Some examples are the vaults of the refectory of the Convent of Christ in Tomar, the work of

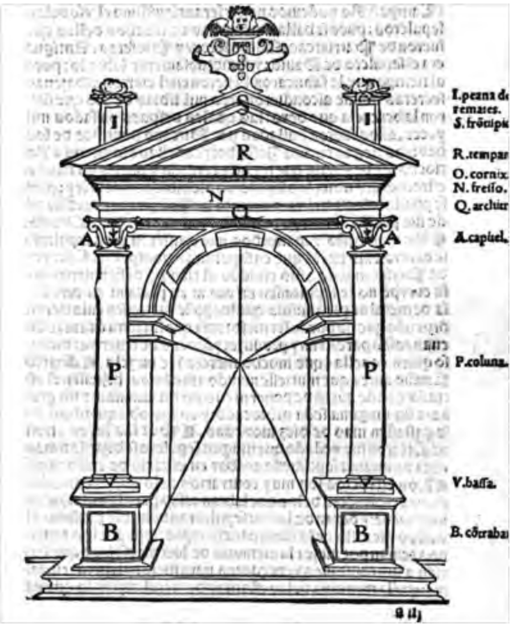

Figure 2. *A tomb with a triumphal arch*. Portuguese edition (Sagredo 1541). Photo: Biblioteca Nacional España (Madrid).

João de Castilho or the Church of St. John of Foz in Porto by the architect collaborator of Rafael in Rome, Francesco Cremonese (Serrão 2002: 56–9). Consequently engineers, architects and missionaries who traveled to India could already take cognizance of some of these references, although the appearance of coffers in the treatises was still scarce.

There is no written evidence in the *Historical Archives of Goa* that the Orders possessed architectural treatises in their libraries (Nunes Pereira 2003: 22). Nevertheless, there are two books that in one way or another should have been known by the master builders who were working in Goa.

The first one is Diego Sagredo’s *Medidas del romano,* published for the first time in Toledo in 1526 and reedited three times in Lisbon between 1541 and 1542 by the publisher of King Joao III, Luis Rodríguez. Among its first pages there is a representation of a tomb with a triumphal arch whose intrados is made up of coffers (with rosettes in the Spanish and French editions and without them in the Portuguese). Their presence goes almost unnoticed, since they have not been referenced in the caption of the illustration like the rest of the elements (Figure 2). The second treatise is the *Terzo Libro* of Serlio published in 1540 in Venice. The representation of the “temple in the surroundings of Rome” (page XXXII) shows a rectangular space sectioned longitudinally that can adapt very well to the shapes of the churches in Goa and especially to the chancels. This treatise reached Portugal at least with Francisco de Holanda, who received it directly from Serlio (Deswarte-Rosa 1981: 240). This Italian architect also included a similar representation to that already cited in Sagredo’s treatise in his *Livro Estraoridnario* published in 1551 in Venice.

Engravings of the fresco *The School of Athens* by Raphael could have been helpful initially in the transmission of the typology if the coffered vaults of the building in the back had not been removed in the early versions (Höper 2001: 63). There are also no references to coffers in treatises such as Vignola and Du Cerceau although some of their design principles appear reflected in the churches of Old Goa (Nunes Pereira 2003: 91–92, 99, 148, 153, 155, 176, 229, 264).

As will be seen below, the first examples constructed with coffers in Goa are based on simple directions and it may not be necessary to have references other than the cited ones to be able to reproduce them. If it had not been an affordable method, it would not have been persistently adopted by all the active religious Orders in Goa (by the Dominicans from 1548, by the Augustinians in 1575, and by the Theatines later in 1639). In fact, Alberti defined these vaults built in the Italian manner as low-cost and low-effort vaults (Alberti [1450] 1991: 310).

4 THE CONSTRUCTION OF THE FIRST COFFERED VAULTS IN GOA

The religious architecture of the Iberian Peninsula was characterized by the massive use of stone. This manner was transferred to Goa even though the only stone available there was laterite, a soft, ferrous volcanic stone that could be easily worked.

The first coffered vaults in Goa were built as an adaptation of Gothic stonemasonry techniques.

From the point of view of stonecutting there is not much difference between carving the ribs for a coffered barrel vault and those for a ribbed vault. In fact, the task is simpler because the presence of the complex keystones is diluted in its form.

One of the earliest cases in which the deployment of construction means can be best appreciated is the chancel of the St. Catherine’s chapel in Old Goa, as the vault was not re-whitewashed in the 1952 restoration by Baltazar Castro (Santos 2017: 245–48) (Figure 3).

It was built in 1550 by order of Governor Jorge Cabral to the north of the archbishop’s residence and of the convent of St. Francis of Assisi. This chapel should not be confused with the cathedral, whose baptismal chapel with a stellar-vault is still preserved annexed to the current Goa Cathedral, also dedicated to this saint (Nunes Pereira 2010).

The chancel of St. Catherine has a barrel vault with an odd number of coffers in the arch, nine like the representation of Serlio, formed by a regular mesh of ribs closed by the extrados with other laterite voussoirs. The construction starts from a horizontal and continuous molding also in stone, supported by brackets which match the arches in depth (in this case nine). The presence of this decoration could also have played an important role in the installation of the centering which

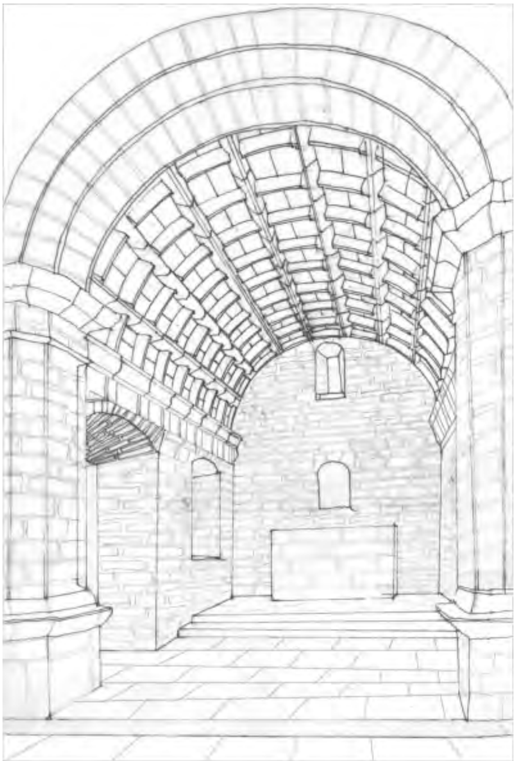

Figure 3. St. Catherine's chapel. View of the chancel with crossing trellis vault and *capialçado* over the door on the left.

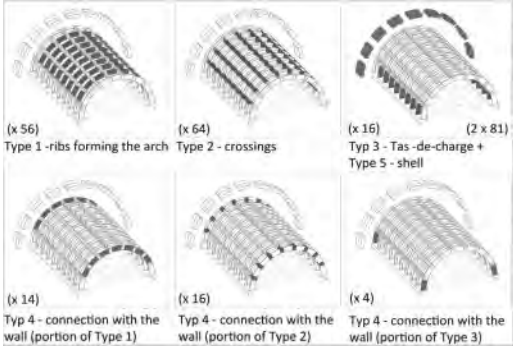

Figure 4. Representation of the different types of voussoirs in the St. Catherine's chapel in Old Goa and amount of voussoirs.

could be repositioned several times during the development of the works to save costs due to the repetition of the form.

The construction of the vault in St. Catherine's is developed from five different types of voussoirs (Figure 4):

- the ribs forming the arch;
- the crossings, horizontal ribs holding the tas-de-charge for the first type of ribs (Figure 5);
- the ribs which form the tas-de-charge of the vault and which could be like the first type;
- the ribs for the connections of the vault with the walls (usually portions of the three previous types);
- the voussoirs that close the grid (in the vault of St. Catherine there are two stones of this type per coffer).

Figure 5. Crossing of a crossing trellis vault. Church St. Augustine, Old Goa.

Table 1. Churches with crossing trellis vaults in the chancel with nine coffers in the arch.

Place	Church Dedicated to:	Founded
Dona Paula	Chapel	1534?
Old Goa	Our Lady of the Mount	1543
Old Goa	Chapel of St. Catherine	1550
Saloi	Savior of the World	1565
Taleigao	St. Michael	1544
Assolna	Queen of Martyrs	1616
Carmona	Our Lady of Succour	1607
Loutulim	Savior of the World (Jesuit)	1581
Old Goa	St. Monica	1606–1627
Pilar	Our Lady of Pilar	1613
Rachol	Church in the Seminary	1609
Rachol	Our Lady of Snows	1576/1596

Table 2. Churches with crossing trellis vaults in the chancel with 11 coffers in the arch.

Place	Church Dedicated to:	Founded
Agassaim	St. Lawrence (Jesuit)	1565
Carambolim	St. John Baptist	1541 (rebuilt early 17th c.)
Curtorim	St. Alex	1597 (rebuilt 1647)
Chorão	St. Bartholomew the Apostle (Jesuit)	1560 (rebuilt 1641)
Old Goa	Bom Gesú (Jesuit)	1586–1594
Curca	Our Lady of the Rosary	1650
Merces	Our Lady of Merces	1613

Eleven other churches with this same grid of ribs in the chancel (and probably with a similar partition of voussoirs) have been found in the region. Four were built in the 16th century and seven in the early 17th century (Table 1). The number of coffers in the arch increased to 11 in seven churches. One of them is the Bom Gesú in Old Goa, which was probably the prototype for the others, especially for those of the Jesuits (Figure 1) (Table 2).

In most cases, the decoration of the arch that frames the chancel is standardized and also presents coffers which match the distribution of the rest of the vault on the front and on the intrados and which are duplicated in the fold between both surfaces. The depth of these barrel vaults varies between nine and eight caissons although we found seven in the chancel of *St. Monica* in Old Goa. Serlio also represented eight in his "temple in the surroundings of Rome".

The constructive development of a ribbed vault with these characteristics, the so-called crossing trellis vault, can be found in the treatise of the Andalusian architect, Alonso de Vandelvira, written between ca. 1575 and 1591 and known from two copies of the 17th century (Palacios 1990; Palacios & Bravo 2012). It contains a total of 15 variants of coffered vaults and domes, although the barrel vaults were not contemplated in the repertoire. Due to their simplicity, they could be easily developed if the others examples were understood (Aranda Alonso 2018).

Vandelvira proposed two ways of constructing these crossing trellis vaults. The first one with *moldes revirados* ("re-veered molds" according to the translation of Palacios) is related to the way of configuring the ribs in Gothic vaults (Palacios & Bravo 2009). In this one, the extrados is adapted according to the position of each rib in the vault because their axes have a vertical orientation.

The second possibility is more logical and simpler: all the ribs in the arch are identical because their axes are always radial to the center of the vault. With this method, the carving work can be almost completely standardized with a couple of templates (Figure 6) (Palacios & Bravo 2009; 2012). In the Portuguese sphere, it seems that the "re-veered" variant was used exceptionally in the refectory of the monastery of Tomar, although R. Lobo attributes it mainly to a matter of aesthetics (Lobo 2020, 184). Only the radial method has been observed in Goa.

Where the vault covers a larger space, then the ribs and the fillings of the lattice will be divided into smaller portions keeping the same principle. This procedure can only be observed when the state of conservation of the vault is not adequate like in the side chapels of the Old Goan Augustinian Church built from 1597 (Figure 7). The nave of *Our Lady of the Mount*, the only example in the region to have such an original marked and regular grid, seems to correspond to this method too (Deshpande & Savant 2001). These smaller voussoirs act as bricks and the vault could be built with a centering like the one that Alberti proposed (Alberti [1450] 1991: 310). This technique could also have been used for the coffered vaults with irregular grids of the cathedral in Old Goa built between 1564 and 1652.

Throughout the entire treatise, Vandelvira emphasizes the importance of planning arches and vaults with an odd number of voussoirs. This principle needs to be always respected even if the coffered vaults can be planned with different types of voussoirs. Lobo highlighted the existence of several examples with an even number of coffers, especially in paintings, leaving a central rib as if it were a spine (Lobo 2020). Observing the distribution of the voussoirs that compose a vault made of stone in detail, the total number will always be odd, as can be seen clearly in the vaults around the stairs in the castle of Chambord.

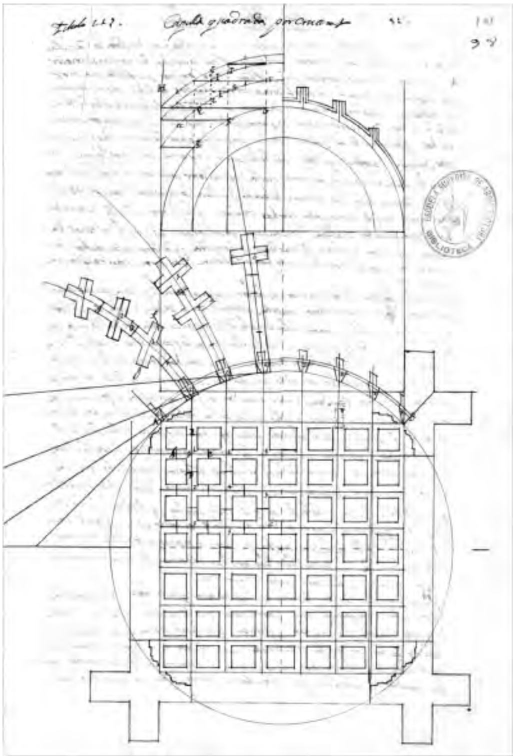

Figure 6. *Capilla cuadrada por cruçeros*. In the section, on the right, the ribs with a radial orientation connected to the crossings' templates; on the left, the "re-veered" (Vandelvira [1670?], 98r.).

Figure 7. Vault of one of the side chapels in ruins of the Augustinian church.

The French example allows the introduction of another variant for the construction of these vaults based on the surface's excavation of compact voussoirs. The relief of the rib and the shape of the mesh are generated without the need to separate the structure into two parts like in the crossing trellis vaults. The vaults of the Church of San Lorenzo in Linhares, probably built around 1630, could have been conceived in this way. The presence of a central rustication in each coffer (seven in the section of the vault in nave and five in the chancel) was favored by this technique.

Although the planning and development of these vaults was not difficult due to the repetition of their voussoir types, they had to be carved and built properly. From the studies of Mendoça (2002: 41) it does not seem very realistic to think that Hindu stonemasons worked with Christians for the construction of churches, although some sources do testify to such collaboration (Caritas 2007: 71).

5 THE EVOLUTION OF THE TYPOLOGY

The Baroque transformation of spaces that took place in Europe ended up reaching Goa. With Carlo Borromeo's *Instructiones Fabricae et Supellectilis Ecclesiasticae*, published in 1577, it was established that churches should be as majestic as possible so that their splendor would impress the spectators without them consciously realizing. This premise caused a long-term change in the use of materials.

The churches built during the 17th century mostly continued with the same typology of a single nave and deep chancel seen to this point. Nevertheless, the way of covering the chancel was slightly modified. On the one hand, variations were introduced in the basic shape of the barrel vault. On the other hand, the caissons no longer presented a strong difference of levels as the crossing trellis vaults, they help to reduce the total weight. Perhaps for this reason, the triumphal arch that framed the chancel in some cases, also began to lose its coffer decoration like the overall vault.

The formal appearance was altered by the construction of windows in the chancel. This desire or necessity was also suggested by the Council of Trent and appears in Borromeo's book (Sénécal 2000: 254). Their introduction was carried out through lateral, small, semi-cylindrical vaults called penetrations that interrupt the continuity of the barrel vault perpendicularly. The surfaces of these lunettes were also covered with caissons and the groin between both surfaces was carved as if it were a rib. The central area can contain one or three coffers depending on the height of the lunettes. With only one coffer, the intersections could be articulated to generate the impression of a groin vault, as occurs in the sacristy of the Bom Gesú church, considered one of the pioneers in introducing this variant. Altogether there are 12 churches with this configuration in the chancel (Table 3).

On occasion, arches were inserted between the lunettes. The presence of these partitions is constant, and necessary from the structural point of view, in the churches with coffered vaults in the nave in the 17th century.

Table 3. Churches with grid in relief in the chancel.

Place	Church Dedicated to:	Founded	coffers/ centre
Benaulim	St. John the Baptist (J)	1596 (chancel rebuilt 18th)	7/1
Cansaulim	St. Thomas	1581 (rebuilt 1632)	9/3
Britona	Penha de França	1626/1655	9/1
Colva	Our Lady of Mercy	1635	9/3
Divar	Our Lady of Pity	1625 (rebuilt 1699–1724)	7/1
Margão	Holy Spirit	1675 (5th church)	9/3
Majorda	Monte Hill Chapel	¿?	
Nagoa	Holy Trinity	1560 (rebuilt 1679)	9/1
Neura	St. John the Evangelist	1541 (rebuilt 1624)	11/3
Nuvem	Holy Family	1695	7/1
Piedade	Our Lady of Pity	17th	9/1
Seraulim	Our Lady of the Pilar	1630/1635	11/3

With regard to the materiality of this variant, a debate can be opened.

If it were built in stone the grid would be excavated on the surface of the voussoir as has been assumed in the case of Linhares and the task would be standardized too (in the arch the number of coffers varies between seven, nine and eleven). Nevertheless, the stones for the intersections would include two cylindrical surfaces which increase the complexity. This would mean that their conception would be similar to some vaults present in such relevant buildings as El Escorial. Analogous solutions found in Vandelvira's treatise [fol. 23r; 79v.-81r.] show that these forms are affordable but require more specialized labor. The presence of the lintels with ruled surfaces in some churches, as for example in the entrance of St. Catherine's or in the cloister of St. Augustine's, could prove these skills (Figure 3). These lintels were very common in the 16th century in the Spanish architecture and they were known as *capialçados*.

The same caisson's form could also be built, in a cheaper way, either with plaster coffers or with plaster molds applied on a previously prepared surface on site. In both cases they would be built from a hemp formwork fixed to an auxiliary structure, probably in timber. This solution would be imposed later in the most sophisticated examples.

In the last step of evolution, the grids became smaller and with more decoration as in the Church of St. Francis of Assisi in Old Goa, renovated in 1661 and already built in stone (Figure 8).

Furthermore, in the Church of St. Hyacinthe in Chicalim, the distribution became more refined because the coffers were distributed diagonally and directly in groin vaults. The most outstanding cases are the vaults with plaster coffers in the Church of St. Cajetan in Old

Figure 8. View of the vaults with the grid in relief carved in the chancel and in the first part of the nave in the St. Francis of Assis church (Old Goa).

Figure 9. View of the vaults with sophisticated plaster coffers in St. Cajetan (Old Goa).

Goa, even if they didn't reach the complexity of some Roman cases such as San Carlo alle Quattro Fontane by Borromini. This church was built by the Theatines from 1650 onwards, configured with a cross plan, a more open chancel and the addition of some vaults with octagonal grids (Varela Gomes 2010) (Figure 9).

The development of these last variants gave rise to churches, such as that of St. Anne in Talaulim or that of the Church of the Holy Spirit in Margao in the late 17th century, considered as churches in purely Goan-style.

The abandonment of Old Goa due to the plague appears to result in the decline of the use of coffered vaults, although the idea of the chancel with a barrel vault framed by an arch remains in new constructions.

6 CONCLUSIONS

The use of coffers in their different variants seems to expand throughout the region from Old Goa with very distinguished prototypes: first the barrel vaults with regular grids built like Gothic vaults with a shell and ribs, the so-called crossing trellis vaults. Then, the barrel vaults with penetrations with still regular reticules with a lighter relief in the middle of the 17th century; and finally, the vaults whose decoration overpowers the surfaces and modifies the orientations of the grids.

The examination of more technical and specific aspects was not possible in this paper. However, we believe that there was a clear standardization in the construction of these vaults that would have accelerated the planning and review of projects and which would have saved costs in the organization and development of the work.

Furthermore, it would be interesting to proceed to carry out measurements of the different cases to find relations because the characteristics could really be standardized by contract. Like other cases brought to light by H. Carita, it was only necessary to change some parameters for the configuration of a new project. Among these parameters, of course, there was the possibility of suppressing the coffers which occurs occasionally until the end of the 17th century and frequently after the abandonment of Old Goa.

This study can also give rise to the investigation of the expansion of this typology and its different variants in other regions. Some cases have been found, for example, in Kerala or Mumbai, although their use does not seem as widespread as in Goa. The architecture in Brazil can be placed at the opposite pole, because this typology seems to have had hardly any relevance there. This fact shows that even under the same government, architecture also had to adapt to the territorial and social circumstances of the place and its original inhabitants.

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History of Construction Cultures – Mascarenhas-Mateus & Paula Pires (eds)

The domes in piperno stone of San Giacomo degli Spagnoli in Naples

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ABSTRACT: The church of San Giacomo degli Spagnoli was built in monumental form in 1540 on a significant site in the city of Naples as a welfare institution. It was commissioned at the behest of Viceroy Pedro de Toledo with Spanish and Neapolitan nobles and Order of Santiago members, and constructed by State engineers. The 1820 renewal of the urban block which contains the church as well as successive revisions strongly altered the 16th century church and hid important parts of its structure, in particular the piperno stone elements. This paper carries out a recognition analysis of the original parts of the church, of which the piperno "scalopped" emispherical domes stand out. They cover the side aisles and the main chapels, and appear to be a unique construction solution within historical Neapolitan building practice.

1 OVERVIEW OF THE RESEARCH

The Neapolitan church of San Giacomo degli Spagnoli, whose construction was undertaken in 1540 by the Viceroy of Naples Pedro de Toledo, is of great importance in the history of Early Modern architecture. This is evidenced by the monumental character of its architectural design, three aisles with side-aisles of five squared domed bays; through the functions provided by the annexed structures; and by the importance of the urban location. Furthermore, the recognition of some singular construction features increases the value of the architecture of the church in the history of construction (Figure 1).

Despite its importance, the architecture of the church in the aspects of form and construction has not been analyzed in depth. This is mainly due to the limited visibility of the original structure following the profound transformations it underwent. In the 1820s the urban block which contains the church and the various structures of the complex – hospital, bank, convent, and confraternity – was converted into a large building to house the Ministries of State (Figure 2). The church survived, being incorporated within the new building, but substantial parts of the original structure were removed or modified, and interior walls and vaults were covered in plaster, hiding the construction features of the 16th century church. In addition to these radical transformations, successive refurbishments occurred over time. Building repairs, and partial reconstructions following World War Two damage brought further changes to the original structure.


Figure 1. The church in the topographic map Du Pérac–Lafréry (1566) and Baratta (1629) in a detail (Elaborated from the maps reprinted in Cantone & De Seta 1986; Di Mauro 1992).

Accurately identifying the 16th century architecture of the church is therefore complex, which requires the cross referencing of various existing sources with material investigations of the structures.

The ongoing study of the church of San Giacomo degli Spagnoli in Naples has been carried out through agreement with the owner of the church – *Real Hermandad de Nobles Españoles de Santiago en Nápoles* – and the University Suor Orsola Benincasa, signed in July 2020. So far, a preliminary general


Figure 2. The church in the project drawings of the Palace of Ministries (Elaboration from the project drawings of Gasse (1820) in Rossi 2008).

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orientation has been undertaken, through a review of available literature, historical iconography, and existing literary sources, as well as through the identification of documentation regarding the 19th renovation, successive renovations, and post-war reconstructions, together with surveys on specific parts of the structure. The cross-referencing analysis has led to identifying elements of the original structure and to re-reading the formal and construction features of the 16th century church. Walls, vaults, and dome added in the 19th century have been identified which has led to ideally restoring the architecturally figurative unity of the former church. Thanks to local inspections and through the removal of plaster from some sections of walls it has been possible to distinguish ashlar masonry blocks and voussoirs in hard piperno stone from those in poorer Neapolitan masonry of yellow tuff and Pozzolana mortar. This highlights some construction peculiarities of the 16th century building of the church.

In Neapolitan Renaissance architecture, it was common to use the two stone materials – both locally extracted – within the same building, usually with a different role due to the stones’ properties. Tuff provides the main masonry – walls, vaults, and domes – whilst piperno stone is used for cladding or in blocks, voussoirs or monolithic pieces for special parts of the building, such as pilasters, columns, arches, portals and window frames, and for elements of architectural order. Their construction, moreover, is referred respectively to distinct technicians, the “fabricatore”, for masonry manufacturing in tuff and Pozzolana mortar and the “piperniere” for cutting and setting the piperno stone (Como 2020; Garofalo 2010:20).

In the church of San Giacomo, identification of the original parts in piperno stone has revealed extensive use of this stone, which is here mainly used for ashlar masonry – rather than in cladding – and in abundance for the numerous arches on pillars which characterize the church’s architectural design. Furthermore, in San Giacomo degli Spagnoli the structures in piperno stone do not only form the architectural elements for which piperno is common in local Renaissance churches and palaces: pillars, arches, cornices, the architectural order of pilasters and the entablature, generally in slabs. Here, extraordinarily, even the hemispherical domes with oculus, engraved by deep meridian grooves at the intrados, covering the five squared bays of each side-aisle, are also built in piperno stone (Figure 3). The construction of domes in voussoirs is unique in the local context, where for simplicity of construction and feature of the local resources the masonry domes are generally made of yellow tuff with imprecisely cut pieces and Pozzolana mortar.

Inspections of the scalopped domes of San Giacomo degli Spagnoli were carried out using a drone survey of the dome intrados making it possible to obtain a detailed dome profile and close-up photos, while, due to mobility restrictions during 2020/1, the planned workshop with students in Conservation, which aimed at removing plaster from the dome intrados to reveal the masonry, had to be postponed. Despite this, the historical study of the church and its transformations, combined with the direct analysis, provided further elements and considerations concerning the use of piperno stone for the domes in the side-aisles, and finally highlighted the reasons for this peculiar building choice.

Figure 3. The scalopped domes over the bays of the side-aisles.

This paper comments on the fields of investigations that served to frame the study and which led to an understanding of why piperno stone was used for the domes as well as identifying reasons, contingencies and the technicians and patrons involved.

The importance of the case-study of piperno ashlar domes in Neapolitan Renaissance lies in the lack of clarity around some significant issues in the development of forms and techniques of vaults and masonry domes that could link construction works and builders across different European regions. The case of the piperno ashlar domes of the church of San Giacomo degli Spagnoli in Naples could in fact provide new data to reconstruct links between Spanish technicians and architects in Italy, and recognize the value of specific solutions obtained by inserting different building cultures into another context.

2 INVESTIGATIONS

2.1 *The foundation. Patrons and builders*

The church of San Giacomo degli Spagnoli, with the adjoining hospital, was founded as a State work in 1540 and designed as the core of the “Spanish Quarter” (Hernando Sánchez 2004, 445) being located near Castel Nuovo and the port, within the new city layout defined by Pedro de Toledo, Viceroy of Naples (1532–52) and master of the Order of Santiago (Hernando Sánchez 1994).

The complex replaced a smaller Spanish charitable building, which had become inadequate. The new foundation to be named after Santiago had been supported by Hernando de Alarcón (1466–1540) (Borrelli, 13–14), Marquis of the Valle Siciliana, knight of the Order of Santiago, who was also at the time Castellan of Castel Nuovo (Suarez de Alarcón 1665, 437–8). To this end, Hernando de Alarcón had obtained papal consent in 1532 and endorsement from the General Secretary of the Order, Francisco de Los Cobos, to whom de Alarcón wrote a thank-you letter in 1533 (Hernando Sánchez 2004, 476, n.139). This was before Francisco de Los Cobos himself would have stayed in Naples between November 1535 and March 1536 when he accompanied Charles V through Italy after the conquest of Tunis.

Together Hernando de Alarcón, governors and confreres of the already existing welfare facility, took care of the purchase of the area for the new premises. The purchase was supported by considerable donations from Spanish-Neapolitan nobles, such as the Duchess of Martina Giovanna Requesens, wife of Petraccone Caracciolo, great-granddaughter of the first castellan of Castel Nuovo, Pascual Diaz Carlon.

When the State took charge of the new foundation, the Viceroy appointed the governors already in place – the Regent of Count Federico Uries, the Viceroy's Advisor Galeota Fonseca, Carlo de Aragón, the knights Pegnalosa and Escrivan, the nobles and knights of Santiago Marcello Caracciolo and Ottavio Pignatelli – responsible for the construction and governance of the new foundation (Borrelli 1903, 15), and defined the rules for the constitution of the church and hospital welfare institution (D'Engenio Caracciolo 1623, 530).

Finally, the Viceroy arranged the procedures for the acquisition of funds for the construction works and future operation through taxation of military officers, in proportion to their role, with a contribution by the State through rents and funds.

The *Cento Continui* of the Viceroy of Naples (100 gentlemen half Spanish and half Neapolitan who had to accompany Pedro de Toledo in peace and war) also participated in the construction expenses (De Lellis, tomo IV, cc. 101r-104v). Their support was acknowledged with the privilege of a patronage chapel, which is fifth on the left, to Saint James. The same Hernando de Alarcón left a generous donation for his patronage chapel, the Alarcón Mendoza chapel, which is the Gospel chapel in the new church, dedicated to St Maria della Vittoria and which would be renewed in the second half of the 18th century (Grossi 2007, 410). The Catalan community, asked by the Viceroy to move their patronage chapel here in 1546 (Hernando Sánchez 2004, 446), built the largest chapel of the church behind the two main chapels at the left transept.

The foundation-stone laying ceremony, confirmed by literary narrative (Hernando Sánchez, 2004, 446:140), was celebrated in February 1540, shortly after the death of Hernando de Alarcón. The construction of the hospital began later, in 1547.

The foundation account shows the complex network of relations between the Neapolitan and Spanish construction worlds through supporters, governors and patrons.

Figure 4. Detail of the topographic map Du Pérac-Lafréry (1566) (from the reprint in Di Mauro 1992); the church and Castel Nuovo are marked with numbers 37 and 10.

As a State work the construction was managed by State engineers and mainly, according to historical sources, by Ferdinando Manlio who directed the construction work in 1547 (Filangieri di Satriano 1891, 99), to whom the majority of design and direction works by Pedro de Toledo works are attributed (Fiadino 2016; Strazzullo 1964, 208–216. The construction of the church should therefore be seen in the context of the urban renovations that Pedro de Toledo carried out during his long viceroyalty (1532–53). These were substantial and led to a new city layout (Hernando Sánchez 1994, 465–6), clearly portrayed in the Du Peérac-Lafrery topographic map (Valerio 2013, 71–2) (Figures 1, 4). As shown on the map, the church is located at a key site (Hernando Sánchez 1994) at the lower right corner of the urban block adjacent to the new viceroyal road – the Toledo road – and along its orthogonal axis, that marks the new Spanish extension of the city linking the harbour near Castel Nuovo with the military fortress of Castel Sant'Elmo on the hill.

In front of the church and during the years of its construction – between 1544 and 1555 – there was reconstruction of the south-eastern corner of the outer enclosure walls of Castel Nuovo, which became the residence of the castellan Pedro Gonzalez de Mendoza, son-in-law of Hernando de Alarcón (Filangieri di Candida 1940, 22–5). These works with the system of moats along the seaside strongly affected the morphology of the surrounding grounds (;Celano 1692, 171; Hernando Sánchez 1994; Rossi 2008, 28) closely linked to the church site.

The reconstruction of the Castel Nuovo enclosure walls was directed by Ferdinando Manlio for the Molo rampart and by Juan Bautista de Toledo for the Marina rampart (Filangieri di Candida 1940, 24–5), for the same salary. Juan Bautista de Toledo was most likely in Rome from 1539 to 1549, collaborating with Antonio da Sangallo the Younger, and in Naples from 1549 to 1559 working for Pedro de Toledo (Rivera Blanco 1984), as recorded in the references of traditional Spanish literature (Llaguno & Cean 1829, 78), literary sources (Ammannati-Valeriano 1603, 286) and the few available documentary sources. It is therefore congruent with his participation in the Neapolitan State works, including the church of San Giacomo degli Spagnoli.

The status of the church as a State work, built by State technicians and managed by eminent figures of government, mainly Spanish or in close contact with Spain, together with the Order of Santiago, suggests the involvement of Spanish architects and connections with other churches of the Order built in Spain.

2.2 *Previous studies*

The lack of in-depth architectural and construction studies of the 16th century church of San Giacomo degli Spagnoli can only be justified by the profound transformations undertaken with the 19th century renovation of the urban block (Malangone 2008).

The historical importance of the venue, of the institution and its welfare and administrative functions have been underlined through the historical analysis of the long viceroyalty of Pedro de Toledo (1532–53) (Hernando Sánchez 1994). The government of the institution and the financial function of the bank have been then analyzed in socio-economic historical studies (Salvemini 2018). The most substantial references concern the history of the foundation and patronage, art works, epigraphs of chapels and sepulchres before the 19th century modifications, which are in literary sources describing the city and churches (Celano 1692, D’Engenio Caracciolo 1623, 529–41; De Lellis 1689, 101r). The most exhaustive report describing chapels and sepulchres in the new layout, also covering the later administrative history and events, was written by Monsignor Raffaele Borrelli, rector of the church at the turn of the last century (Borrelli 1904). The study of decorations and art works in the church chapels are referred to in the documents of San Giacomo Bank from its foundation to the 19th century (Grossi 2007).

However, these studies lack analysis of the architecture, except for some comments which underline the curious asymmetry of the church’s architectural layout, justifying it through a refined relationship with the urban context: to allow observation of the pier from the central axis of the church, its right side was arranged along the road and consequently large chapels could be built only along the left side (Celano 1692, 40–4).

In history of architecture literature, although the uniqueness of the layout of the 16th century church has been emphasized, with the side aisles in five bays covered by domes with oculus and grooves along the meridians (Pane 1975, 256–7), the repercussions of the form of construction aspects have not been investigated. Moreover, the original parts of the building have not yet been identified from the 19th century additions.

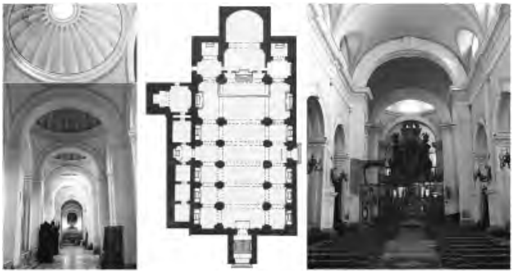

Figure 5. Church plan and pictures of side and central naves.

Observations concerning construction aspects can be found in Blunt (1975, 30), who stressed the great use of piperno stone, which he recognized in the dome ribs, as it could be seen in the main chapel in the epistle after its restoration in 1951. But beyond these general observations, no one thought that the shape and material of the domes would imply a specific construction technique.

2.3 *Architectural layout*

The church of San Giacomo degli Spagnoli is no longer visible as an isolated architectural design because it is inside the palace built at the beginning of the 19th century, today the Municipal seat of the city of Naples. The right portal of its main façade leads through a staircase to the upper level of the church and crossing the entrance, the architectural structure can be read.

The floor level of the church stands on a high podium; massive arches on pillars – enframed into an architectural order of parastas based on high pedestals – define the church in three aisles, with transept and a deep-apsed chancel made of two spans at the back with the main chapels on both sides (Figure 5).

The central nave and transept are covered by barrel vaults with lunettes, and there is a sail vault over the transept crossing. A dome with lunettes is on the contrary odd above the first span of the chancel, over the main altar, and the main chapels on the sides are roofed with domes, a dome on drum at the gospel side, and a saucer dome scalloped at the intrados at the epistle.

The side aisles, divided into five square bays bounded by massive arches on pillars, are covered in a peculiar way by hemispherical scalloped domes on pendentives, with an oculus at the key. They are similar to the main chapel dome on the epistle side, which is instead a saucer dome without the oculus.

With this sequence of domes on the side aisles, the layout of the church appears to be designed to emphasize the progression, span after span, towards the main chapels. The large barrel nave leads to the altar, highlighted by the main dome, and to the precious sepulcral monument just behind it of Pedro de Toledo and his wife Maria Ossorio, realised by Giovanni Merigliano da Nola, and here placed by his son Garzia in 1572 (Loffredo 2015).

2.4 *The 19th century renovations*

After the Napoleonic Suppression of the San Giacomo church and hospital, with the Bourbon Restoration in 1816 the Reign government decided to build a large Palace for the Reign Ministries into the urban block of San Giacomo containing the church, hospital, bank, female monastery, prisons, and the Spanish Nobles Confraternity.

In order to proceed with the renovation and also to reach an agreement with the supporters and descendants of the founders of the Spanish charities suppressed during the Napoleonic period (Salvemini 1999), the State offered the Spanish Nobles Confraternity the ownership of the church in exchange for their propriety, and from this the private ownership of the church dates back.

The palace was realised through partial reconstructions and wall integrations, building a new façade for the entire block and modifying the original masonry structures, which were thereby strongly affected or re-built, embeded inside the church of San Giacomo (Malangone 2008, 155). The construction works started in 1819 and were completed in 1825 (Venditti 1961).

The church modifications were carried out for two main reasons: to adequately contain the church in the volume of the new building, and to bring it back to unity and decorum with the annexed functions. For the first purpose, the most prominent domes and vaults were removed, causing major alterations. The original dome on drum over the crossing transept, which can be seen in iconographic documentation of the city, was demolished and replaced with a sail vault, and the main arches and barrel vaults of the nave and transept were also altered. A new lowered dome with lunettes on pendentives was raised further back on the chancel. Similarly, all the extradosed domes covering the left side chapels were demolished and replaced with low skylights. Only the domes on the main chapels and on the side-aisle bays were saved.

To restore the church unity and decorum and its functions, refurbishments were made to arrange a service room and sacristy on the left side of the chapels, and a plaster coating was applied to the wall surfaces of the church partially modifying the decorative apparatus of the architectural order and the elements. The left side chapels, reduced in depth, were separated from the church closing the access arches and the fourth chapel, located in front of the church side door, was used to enter the service rooms placed in the chapels.

After these works structural problems occurred, and it was necessary to carry out, between 1896 and 1903, repair works consisting of sub-foundations, rehabilitation of the main arches, and a new remaking of plasters and flooring (Borrelli 1904, 24).

The major changes to the original church highlight the complexity of identifying the original church structures. The cross-referencing analysis of historical data compared with the actual state and with reference to successive modifications – including the partial reconstructions following World War Two damages – allowed exposure of parts and elements of the 16th century church within the actual structure, in order to observe their peculiar construction features (Figure 6).

Figure 6. Surveys on arches and pillars by plaster removal.

2.5 *The church structures in piperno stone*

Plaster removal in several parts of the church showed the wall face of the original structures, leading to recognition of the architectural elements of the former church built in piperno stone and their features. Blocks and voussoirs of piperno stone outline three systems of arches on pillars set at the same height: at the opening on the side-aisles, along the side-aisle bays and at the opening on the chapels. It was also possible to see that the main arches on pillars at the crossing are in piperno blocks and voussoirs, though largely rebuilt, while the pedestals of heavily remade architectural order and the transept wall are in piperno slabs.

The scalloped domes are set on a piperno annular impost cornice above the extrados of the four arches on pillars, bounding the side-aisle bays with the mediation of pendentives. These emispherical domes with oculus and deep grooves along the meridians, similar to a shell rotating around the central axis of the dome, were found to be in piperno stone too. Therefore, the massive arcades system, which constitutes the piperno stone skeleton of the church architecture, culminates upward with the piperno stone scalloped domes in a longitudinal sequence along the side-aisles.

Although inspections and analyses have not been completed, the use of piperno for these domes can be deduced by a number of considerations. First, the historical study has shown that these domes are among the original parts of the 16th century church. Moreover, falling plaster at some places of the intrados showed a dark coloured surface which suggests the presence of grey piperno rather than yellow tuff. Lastly, according to the principles of building feasibility, the considerable thickness of the shell-shape intrados, with circular profile grooves about 20 cm deep and about 49 cm wide at the base, and plane ribs about 33 cm wide at the base, requires a masonry structure rather than just plaster for the emerging volume of the ribs (Figures 7 and 8).

Figure 7. A rendering view of one scalloped dome from the three-dimensional survey (L. Repola UniSOB workshop).

The 1951 restoration, supported by the Spanish State, of the main chapel to the epistle damaged during the war, provides further evidence to favour piperno construction of the dome. During the restoration, plaster was removed from arches, pillars, and cornice, as well as the dome intrados on the meridian ribs, the ring connecting them around the oculus, and at the key. Although it is not entirely clear whether this dome – which is lower than the domes at the aisles and with obstructed oculus – was reconstructed or restored, the mere fact that it is in piperno stone sustains the thesis of the use of piperno for the original domes. In fact, even if the dome had been completely rebuilt, the exceptional use of piperno stone would be explained by the intentional re-purposing of the original features, proving therefore that the original domes with meridian grooves were made of piperno stone.

Observing the texture and colour of the piperno here exposed, the continuity of flames and inclusions of the stone in ribs and ring around the oculus, leads to the assumption that not only the bared ribs are in piperno but the whole dome. This was extraordinarily made using a single block of stone, carved at the intrados in the form of a scalloped dome. Of course, it cannot be directly deduced that the domes of the side-aisles were realised in the same way, and particularly because of their different shape, but certainly its material consistency strongly suggests the use of piperno for the original domes of the side-aisles.

The recognition of the architectural elements of the church of San Giacomo degli Spagnoli in grey piperno stone highlights the primary role of the construction in blocks and voussoirs of piperno in the architecture of the church. The extraordinary abundance of piperno stone walls then appears to demonstrate an easy supply due, presumably, to being a State work.

3 CONCLUSIONS

The plaster removal at the intrados of one of the scalloped domes of the side-aisles is the next target for completion of this study. Only by revealing the wall face will it be possible to find the necessary evidence to understand the way the stones have been laid. This will confirm the investigations carried out by interweaving the historical study with the analysis of the actual structure which led to a consolidation of the thesis concerning the use of piperno in the scalloped dome construction and to understanding the peculiar construction choice.

The decision to construct the dome in piperno voussoirs, or even carving a single piperno block, is derived from the intentional shell-shape of the dome intrados, which was the symbol of reference for the Order of Santiago. The more tender and porous tuff stone, with large internal voids, would not have allowed the realisation of precise profiles of the shell-shaped intrados. The greater hardness of the piperno would instead allow an effective sculptural rendering of the decoration at the intrados.

Figure 8. The piperno stone exposed at the dome intrados of the restored main chapel and the domes covering the side-aisle bays.

The choice of material consequently involves a technical construction choice: the construction of a dome in voussoirs that could only be achieved through the geometric control of shapes and by the cutting of the elements. The propensity for a technical choice of this type, which is typical of a construction culture of the Spanish area, suggests the involvement of Spanish technicians in the construction works, an hypothesis that is congruent with the characteristics of the work itself. In the same way, the large number of parts built in piperno ashlar masonry demonstrates a strong cultural, technical and constructive Spanish presence. The function and patronage of the church and the annexed structures involve contamination and influences between the local construction culture and the Iberian, that can be explained through political links, relations between patrons and builders and the material culture of the specific historical period.

The peculiar design of domes in sequence on the side-aisles refers to the architectural experiences in building St Peter's in Rome under the direction of Antonio da Sangallo the Younger. This aspect suggests the actual contribution of Juan Bautista di Toledo in San Giacomo degli Spagnoli as reported by literary sources.

Moreover, the shell-shape intrados, besides recalling the shell of Santiago, refers to architectural elements designed by Donato Bramante – apse of Santa Maria del Popolo, San Pietro, Nymphaeum of Genazzano – which also had a great influence within the Spanish context. A first reference in the Iberian area seems to be the sacristy dome of the cathedral of Murcia (Calvo López et al. 2005) dated 1525, attributed to the design of Jacopo Torni and the execution by Jeronimo Quijano. It is within the work of Jeronimo Quijano that we find the shell motif strongly present in the intrados of domes, semidomes and vaults (Gutiérrez Cortines 1987). In this respect, the Spanish connection appears very strong.

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History of Construction Cultures – Mascarenhas-Mateus & Paula Pires (eds)

Local interpretations of classical models: The architecture of San Antonio mission churches, Texas

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ABSTRACT: During the 18th century, in the current metropolitan area of San Antonio, Texas, five Franciscan missions were established along the local river. The comparative analysis of three of these San Antonio missions churches with European models demonstrate some recurring elements, certifying a specific design attitude that may be linked to architectural innovations undertaken in Italy during the Counter Reformation period. Adoption and adaptation of the European technologies of quarrying and dressing stones were also carried out. The building surveys and archival research reveal that stone for wall construction was quarried nearby, cut into broken ashlar stone blocks to create a regular decorative pattern. San Antonio Missions, a UNESCO World Heritage Site, are definitively authentic syncretic works, built by the Indians for their own use under Franciscan guidance, incorporating imported cultural models and construction know-how.

1 INTRODUCTION

Nowadays, it is still possible to visit five Spanish missions in San Antonio, Texas, founded in the early 18th century, thus before those established in New Mexico and California. That the San Antonio missions were awarded World Heritage status in 2015 is a testament to their importance for understanding the history of Spanish colonization and evangelization of native peoples in the New World.

During the years in which they were active, the missions were important in refining the evangelization strategies undertaken in territories governed by the Spanish Viceroyalty. The missions served to test new design prototypes and construction techniques based on the adaptation of medieval and classical prototypes and traditional construction materials and techniques appropriate for evangelizing the native people within the unique geopolitical conditions they found in the Americas.

Established in 1718, the San Antonio de Valero mission was initially located on the east side of the San Antonio River; but with this exact location still uncertain. However, we do know it moved to its current location sometime between 1719 and 1720 (Ivey 2018, 23). The new site was most likely considered more strategic because it was near the river providing irrigation for the surrounding agricultural parcels through a system of *acequias* or water channels (Habig 1968, 124); and the new site allowed for a more effective surveillance of the surrounding agricultural parcels and providing regulation of commercial activities along the *camino*, leading toward the eastern territories.

The chronology of the construction of the mission San Antonio de Valero is complex. The mission church, which began in 1744, was never completed (Felli et al. 2019, 743). However, the mission's site location and overall planning was considered successful and imitated in the other missions. The first such mission, San José y San Miguel de Aguayo (1720), was moved several times before settling in its current location in 1724. In this case, the main church also came much later (Leutenegger 1975, 3–8), as did the churches of the San Juan Capistrano, San Francisco de la Espada, and Nuestra Señora de la Purisima Concepción de Acuna missions. The latter, founded in 1716, was moved to its current location to take advantage of an existing irrigation channel built for San José (Ivey & Fox 1999, 5). By 1731, the town, then called San Fernando de Bexar, had expanded along the banks of the San Antonio River within a system of *acequias* contiguous to the boundaries of the family plots or *suertes* and protected by the *presidio* (military installation) located near the center of the settlement (Lombardi 2016, 201).

Every aspect of life in the missions was entrusted to the care of the Franciscan friars, mostly from the convent of *Santa Cruz de los Milagros* in Queretaro (Mexico), which was in charge of four of the five San Antonio missions. However, when the first expeditions to California began in 1770 (Preta 1915, 75), and by 1773, all Texan missions were placed under the jurisdiction of the convent of *Nuestra Senora de Guadalupe* in Zacatecas (Mexico), which already had produced

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the prosperous mission of San José. Moreover, the limited resources for investment in this area, due to the Franciscan expansion toward California, affected the San Juan Capistrano and San Francisco de la Espada missions with their building construction costs were reduced as far as possible. This led both to a streamlining of the architectural forms and the simplification of the adopted construction techniques.

The role and importance of the settlements was steadily diminished due to the constant threat of Indian raids (Leutenegger 1977a, 2) during a period of mission secularization beginning in 1793 due to the increasing political uncertainty that led to Mexico's independence from the Spanish Crown in 1821 (Leutenegger 1977b, 36; Pastor 1955, 308). For these reasons, this study focuses only on the first three missions in the period between 1718 and 1773. This timeframe marks the greatest commitment and achievement in Franciscan mission architecture. Consequently, these Franciscan missions display similarities in their site plans, ground plans, materials and construction techniques and can return an exact and detailed overview of mission architecture in Texas during the 18th century.

2 EUROPEAN DESIGN INFLUENCE

Analysis of the architecture of the San Antonio missions together with the best-preserved buildings have allowed us to compare numerous relationships with traditional and modern European design methods, involving both a practical approach and its corresponding symbolic and formal aspects (Ivey 1990).

First, the traditional choice of fencing off the settlements launched a functionally effective innovation. The decision to build perimeter walls for the missions, not considered in the earlier phases, was implemented overtime due to the Indian raids of some tribes, the "Apaches, […], que desde la Ereccion de San Antonio, siempre han hecho, matando soldatos" (OFM, *Missioni*, M.34, *Mexico. Relationes et Epistolae*, 286*v*: letter Virrey de la nueva Espana. November 9, 1733)

The fortified enclosure was used to house the converted Indians: The structure consists of a perfect square footprint of stone and lime; "each side is two hundred and twenty varas long and has a door. The dwellings of the Indians are built against the wall from five and six varas in length and four in width" (Solis 1767). This solution does not find specific precedents in architectural treatises of the time.

Examples of similar layouts can be found in some settlement plans dating from the 17th century, such as the village of Cervia Nuova, a rather fitting reference, located near the Adriatic Sea in the former Papal States. The town was entirely rebuilt to great international acclaim. The complex, which included both Augustinian and Franciscan convents, featured fortified walls, which had no defensive purpose but were instead designed to house the poorest population (Benincampi 2018, 111–113). Common support facilities were located in the corner (Roca De Amicis 1990, 270). An earlier version of the large square courtyard or citadel with surrounding stone wall to which apartments are added can also be found in the Lazaretto type that first appeared in Venice in 1423 with the building of Santa Maria di Nazareth (a.k.a. *Lazzaretto Vecchio*) and repeated in Milan and Bergamo (Figure 1).

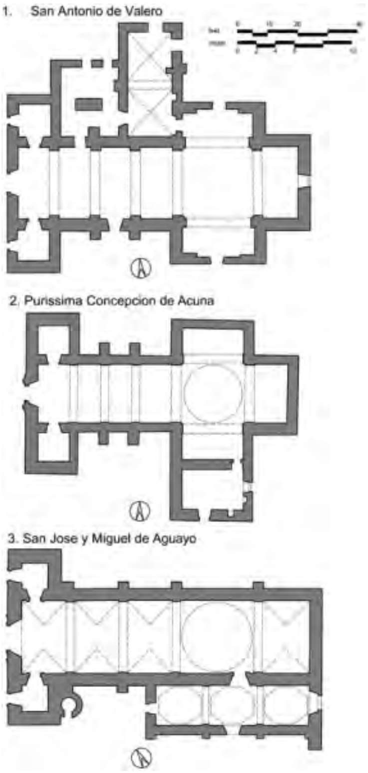

Figure 1. Plans of the three San Antonio Mission churches.

The Franciscans considered symbolic and formal aspects important in the articulation of the overall site planning and in the ornamental articulation in the mission churches. The Friars based their missions on the medieval abbey, a self-sufficient settlement with surrounding agricultural fields. In San Antonio, each of its missions had an associated *ranchería*, a site specifically dedicated to the breeding of cattle. Inside the great atrium court or citadel, various craft activities and religious instruction took place. The church was the core building within the mission complex which dominates through its monumental size, height, and shape. The bell towers, located on the west entrance of the church, give the complex both a majestic grandeur and a military character. The greater height of the towers provided a privileged observation point for the surrounding landscape and performing a defensive role.

The Concepción, San Antonio, and San José mission churches are all based on single nave plans with western entrance facades dressed with Baroque ornament. The prototype can be traced back to the Franciscan manner of building mendicant churches, simple and plain buildings based on a Latin cross plan influenced by the design guidelines of the Council of Trent (1545–1563) and supported by St. Carlo Cardinal Borromeo (1538–1584) in his *Instructionum Fabricae* (1577) which in the wake of the Counter Reformation had been broadly adopted by the new religious orders: the Jesuits, Barnabites, Oratorians, and Theatines as well as the Dominicans and Franciscans who exported them overseas when, in 1567, Pope Pius V (1566–1572) granted "facoltà acciò che i Regolari mendicanti potessero supplire la mancanza dei secolari" (APF, *Scritture riferite nei Congressi. America Centrale dal Canada all'istmo di Panama*, vol. 1, 182*r*) in the missions, as authorized by the King of Spain, Philip II (1527–1598).

3 REINTERPRETING RELIGIOUS MODELS

The reduced transept, single-nave church, was used as a model by the Salamanca architect and theorist Simón García (1649–1694). In his treatise, *Compendio de arquitectura y simetria de los templos* (1681–1683), the author, adopting classical authors such as Vitruvius, Euclid and Serlio as his reference, proposed an effective tracing method for single nave 'temples' through applying rigorous numerical relationships and geometric layouts. The influence García's treatise had in the New World is well known. The layouts and proportions he implemented have been recognized by various scholars in various Franciscan constructions in New Spain, among which, of relevance to this study, is the mother church of the Franciscan Order in the Convent of Santa Cruz de los Milagros in Queretaro (Font Franci 1999, 183–192).

The Council of Trent design guidelines likely inspired Garcia's solution of a single nave with reduced transept, with a raised presbytery as implemented in churches in Europe and Queretaro. This arrangement would have helped draw the attention of the worshippers to the main altar, similarly and equally effective as in the case of mission churches, where it was necessary to effectively engage the congregation. As an ideal space for catechization, the richly ornamented *retablo* and usage of natural light highlighted the celebration of the Eucharist. Compared to the 16th century when conversion was taking place through outdoor assemblies in the so-called *capillas apiertas* (Schuetz & Miller 2000, 763), by the 18th century the emphasis was placed on the interior sacred space where the community was called to gather at least during morning and evening gatherings (Schuetz 1980, 242). In addition, the orientation of the church kept the traditional alignment toward the east (facing the rising sun) as an expression of the resurrection of Christ corresponding with the daily cycle of renewal. The same arrangement of the openings aimed to create on certain days of the year lighting effects to astonish the natives and demonstrate a manifestation of the Divine in the cycles of the seasons and feast days. The Roman Catholic Church over the centuries had awarded financial and social support to the study of astronomy primarily for calculating the day of Easter for each year. Since antiquity the Church decreed that Easter should be celebrated on the Sunday after the first full moon after the vernal equinox when the hours of daylight and darkness are equal (Heilbron 1999, 3). More specifically, a study conducted with the aid of digital models has allowed us to confirm that in the Church of Concepción, Marian festivities were celebrated with sunbeams illuminating the presbytery and the *capocroce*. Similarly, in the Church of San José, an articulated solar geometry was revealed on the days of the solstices and equinoxes, with the probable syncretic intent of integrating pre-Hispanic and Christian traditions.


Figure 2. San José's light virtual reconstruction, June, 8–25.

As mentioned, this exceptional use of astronomy for religious purposes was a long-lasting tradition. Even prior to renovation of the choir of the basilica of Saint-Denis (France) carried out in the Low Middle Ages, light had been used as an *instrumentum regni* or, more appropriately, as a means to reinforce the divine message of salvation intrinsic to Christianity (Panofsky 1962, 130). The friars of the missions therefore engineered the *modus operandi* adopted in the past but updated this according to the modern catechesis objectives. In fact, if in Gothic churches, light was a central element, in Texan buildings, solar illumination becomes an accessory to conversion, an integral part of the purification rite of baptism: a complex ceremony that identified (among others) the entrance portal as a threshold, i.e. the passage from paganism to faith, as also evidenced by the articulated and symbolically meaningful decorative treatment of the elevations (Figure 2).

4 MEANING OF THE DECORATION

A letter addressed to the General Commissary Juan Antonio Abasolo by Ignacio Antonio Cyprian (College of S. Fernando – Mexico, October 27, 1729) clarifies that thus far discussed: "La del Senor S. Joseph en el Rio de S. Antonio […] tiene esta solo un Misionero, y se conserva eretta el mismo que en su institucion puso N.V.P. Marquit: tiene mas de docentas personas de las Naciones Mezquites, y Pastias; no solo cumplen con la

Iglesia todos, sino que frequentan tambien los sacramentos entre ano […]: tiene Convento con claustro cerrado, y losteria: tiene Iglesia mui curiosa, y capaz para mas de dos mil personas" (OFM, *Missioni, M.34, Mexico. Relationes et Epistolae*, 310*r*).

Hence, the church appeared "mui curiosa" to the friar. Such a statement probably originated from observation of the complex surface articulation of the façade, with its decorative richness probably representing the highest point of artistic and technological research and craftsmanship in the San Antonio missions. If the interior of the churches is still today very simple, having no decoration with the sole exception of the *retablo* (imported from Spain), placed at the end of the nave, and the exterior west facade indicating the work of skilled artisans.

In Concepción, for example, the decorative treatment appears based exclusively on the use of simple ornamental forms, organized according to essential compositional lines. The equilateral triangle symbolizes the Trinity, serving as a clear exemplification of a theological concept. The references to the theological principles are not the only themes identified, we can also note a precise intention to celebrate the church as the temple of God. The insertion of a statue of the Virgin inside a niche above the entrance portal as well the use of Ionic columns, a female attribute, frame the niche affirming the dedication of the church to the Virgin, while the lush vegetation around the portal capitals can be interpreted as a reference to the temple in Jerusalem. Certainly, the idea that the New World was an expression of a new Jerusalem was widespread (Tuzi 2017, 303). In this regard, the first twelve Franciscans who arrived in Central America in 1592, following Fray Martin de Valencia, have been called "Apostles" and one of their intentions was precisely to prepare the world for the coming of Christ. Publications describing the recently discovered lands of the Americas by making explicit references to Jerusalem and Solomon's temple had proliferated for decades.

In the first half of the 18th century, the search for a syncretism guided by images was a tool to allow the numerous tribes of Coahuiltecans a gradual approach to religion through the use of metaphorical images and symbolic ornaments, such as the sun and the moon, which respectively embodied the divinity and the people (James & Leone 2011, 58) (Figure 3 and 4)

Such figurative syncretism was generally developed in the facade of San Antonio, albeit within the scope of a greater refinement of style. In Concepción, European references are widely included, such as the carved relief of the cord of St. Francis with eight knots placed to underline both the Franciscan conventual coat of arms and the fringe of Alcantarin friars. The columns are Solomonic to seal the sacred role of the building. Concepción's geometric images are diagrams. In San Antonio, a theological hierarchy is expressed by the horizontal arrangement of the statues in contrast with the vertically descending line in the center of the façade, moving from the sky to the human nature of Jesus (as suggested by the monogram of the Virgin placed on the portal keystone). The portal, in such a context, represents the threshold to salvation, granted through baptism and admission into the έκκλεσία or *ekklesia* community, the Heavenly City represented by the mission church. The more sophisticated meanings were communicated through a formal experimentation that is associated to liturgical ritual, and ways to experience the metaphysical in the physical world of visual form, sound, smell, and light. Hence, the figurative model of San José represents a pivotal point, reaching an innovative balance between the need both for catechesis and for expressing the unique salvific role of the Christian community of the Americas.

Figure 3. *Concepción* façade (photo by the authors).

Figure 4. *San Antonio* façade (photo by the authors).

Here, the facade layout rigorously follows the Counter Reformist criteria. The patron saint takes the center stage, dominating the facade. Next to St. Joseph are St. Francis and St. Dominic, surrounded by rich floral ornaments of Spanish influence: a wealth of details demonstrating the skills (those of craftsmanship) that had developed in Europe, and in parallel in New Spain, and that led both to continental Rococo's sculptural expression and to Iberian hyper-decoration. They both fashioned San José's ornamentation, made

Figure 5. San José façade (Photo by the authors).

through accurate and detailed stone carving, similar to that utilized in numerous religious constructions built at the end of 17th century in Spain, such as the sanctuary of St. Ignatius in Loyola (Benincampi 2017).

If the church's façade upper-level recounts the missionary activity's role in the New World, the lower level focuses on the Marian theme, clearly establishing a continuity of discourse between all three missions. Mary is depicted as the gate for the peoples and nations and channel of grace. The Queen of Heaven is placed above the main door in the center with her hands joined in prayer, the moon at her feet and clothed with sun. Mary is represented as the mother of Christ in glory, probably connected to the iconography of the pregnant Virgin of Guadalupe and emphasized by the putti in the surroundings (typical Marian attributes). On both sides, Mary's parents, Joachim and Anne, are placed in niches to reaffirm the earthly nature of the mother of God and, consequently, of her son. The references to the religious affiliation of the Dominican and Franciscan friars flanking the statue of St. José holding the Child Jesus above which is positioned at the cross, all of which are treated with theatrical sumptuousness. Thus, a precise communication strategy is adopted, interconnected with architectural innovations, that were also carried out at the same time and elsewhere in New Spain (Gustin 1969) (Figure 5).

Yet not everyone had to agree with this glitz. For example, Pedro Ramirez de Arellano (presiding father since 1780 in San José) wondered: "como hemos de proveer de lo necesario nuestras Iglesias, pagar oficiales, y mayordomos, y surtir de los necesarios à los pobres Indios?" (OFM, *Missioni*, M.43: *Mexici Messiones*, 153*r*-156*r*: letter addressed to the college of Zacatecas. January 20, 1780).

5 LOCAL CONSTRUCTION PRACTISES

The refined technical ability of the local stone carvers is underlined by Juan Augustin de Morfi, "lector jubilado, e hijo de la provincia del Santo Evangelio de Mexico", who writes "no one could have imagined that there were such good artists in so desolate a place" (in Schuetz 1980, 279), probably referring to the façade of San José. Such ambitious goals required expert master builders, able to create architectural buildings adequate to the purpose. This was a challenge in the Texas missions because of the low availability of specialized workers in the territory. The most skilled architects rarely frequented the borderlands, both for the hazards posed by the remote setting and the lack of commissions. It was easier to encounter master builders.

According to the available sources, the design guidelines and principles were set by the Franciscans – who were not, however, authorized to manage the construction site due to the multiple previous collapses of the structures built under their direct supervision. The constructions of the San Antonio missions therefore were carried out under the direction of the external expertise of a master mason (Ivey 1990, 43–44; cf. Habig 1968). This is confirmed, for example, by the case of the church of San Antonio, where the maestro Dionico Gonzales and the friar José Lopez agreed, through a *maestranza* contract, on each holding individual responsibility for completing the façade wherein the master was responsible for finding the stone while the friars provided the tools (Ivey 1990, 47; cf. McDowell 1997, 16).

Regarding approaches and methodologies for designing and proportioning the spaces, the detailed architectural survey of the three mission churches revealed that they were carefully proportioned through the use of pre-Euclidean geometry, based on the use of primary forms (such as circle, square, rectangle), combined together according to linear schemes, eventually enriched by harmonic mathematical ratios such as the golden section (the *sectio aurea* or *proporcion divina*). Hence, there is a use of techniques consolidated by tradition and canonized by continuity of practice (Lombardi & Beeson 2017; Schuetz-Miller 2006).

Environmental conditions were primary decision-making factors, such as the proximity to the river, the stability of soil foundations. In the case of the Concepción and San Antonio constructions, the walls were built on limestone banks. The topography of the site ultimately determined the selection of the specific building site's location. Another aspect was the scope for sourcing suitable building materials nearby, mostly wood and stone.

All these factors led to the adoption of stone (stone masonry) for the constructions. Stone offered numerous advantages due to its thermal inertia and properties, well performing in the hot-humid climate of the region, equally unsuitable for unbaked earthen materials that instead returned only a short durability. The adoption of stone also ensured greater resilience, low vulnerability to hurricanes and floods, as well as low risk to fires, which were frequent and very dangerous here as in Europe.

Table 1. List of the master builders active in San Antonio.

Period of activity	Name	Ethnicity	Origin	Task
1740(ca.)–1744	Antonio Tello	Spaniard	Zacatecas	maestro de abanil
1748–1759	Gerónimo de Ibarra	Spaniard	S.Luis Obisp	maestro de abanil
1748–1756	Felipe Santiago			maestro canteiro, maestro carpinteiro, maestro escultor
1750s–1760s	Nicolas Albañil	Tilpacopal		maestro de abanil
1762–1763	Mariano Ángel Galín y Anglino			maestro carpinteiro, maestro escultor
1761–1765	Joseph Palafox			maestro de abañil
1765–1767	Estevan Losoya (?–1767)	Indian	Aguascalientes	maestro abanil
?–1767	Pedro de Alcantara	Papaya Indian	San Antonio	maestro de albañil
1767–1773(?)	Dionico Gonzales (?–1787)	Spaniard		maestro escultor, maestro de albañil
?–1779	Joseph Padron (?–1779)			mayordomo of the quarrying for the church at San Juan
1773–1793	Antonio Salazar (1733–?)	Mestizo(criollo)	Zacatecas	maestro de albañil
1772(ca.)–1805	Pedro Huisar(-)	Mulato(mestizo)	Aguascalientes	maestro carpinteiro, maesto escultor, agrimensor
1790s	Jose Antonio Bustillo	Pampopa		
1790s	Juan de Dios Cortez	Xarame		

The stone's mechanical properties provided effective structural building stability and hence greater durability, with limited maintenance and repairs.

The presence of a nearby quarry was also noted by Friar Morfi, who recalled the presence of a sedimentary limestone quarry of tufa stone, similar to travertine, near Concepción already in 1777. This stone was used both for the nearby mission structures and for those of San José. The stone was light and porous and, once extracted from the quarry, hardened after a few days; after being installed, the stone blocks and rubble assembled with mortar behaved as a monolith (Morfi 1935, 62–63; cf. Habig 1968).

Additionally, Ferdinand Roemer, a geologist traveling to Texas in 1846, wrote in his notes: "The material used in the construction of this building [San Jose] as well as the other Missions is composed of two kinds of stone. The one is a light, porous, tuffaceous limestone, or travertine, which is also found in many parts of Germany, […] where it is valued highly as a building material on account of its lightness. This stone formation finds its particular origin in the deposits of springs containing lime. The cupolas and arched ceiling of the churches in the Missions are built of this material. The other stone used is a greenish gray limestone, containing clay, which has the peculiar property of being almost soft enough to be cut with a knife when taken from the quarry, but later hardens when exposed to the air" (McDowell 1997, 17–18; Roemer 1935, 128–129) (Table 1).

These two settlements were about three and a half kilometers apart This is a reasonable distance for transporting building stone. A similar distance also separated Concepción and San Antonio, just over four kilometers. Yet, this stone was not used in what later becomes known as the Alamo. The reason is not known but it may be motivated by the personal preferences of the master builder, who was in charge of selecting the quarry as well as reasons related to quarrying, the ease of stone extraction and means of transportation. Near the river's spring, in Brackenridge Park, a more compact fine-grained limestone could be found, which was also more suitable for engraved decoration work than the other one, similar to travertine (Ewing 2008, 50–54).

It also seems possible to outline an evolution in the construction practices. Concepción embodies a more archaic model. The roof was shaped through a sequence of stone barrel vaults (*bóveda de cañon*), with the bays marked through transverse arches, which also play the structural role of effectively directing the outward truss to the perimetral walls reinforced by pillared buttresses (*estribos* or *contrafuertes*). At the center of the cross plan, in the capocroce, a circular dome (*cúpula* or *media naranja*) was placed, mounted on a drum which was supported by pendentives (*pechinas*), taking the role of the formal, geometrical, structural and symbolic transition from the squared space underneath. The dome and vault outward loads were contained by thick rubble masonry walls, reinforced by solid pillared buttresses. The stone walls featured broken and random ashlar blocks of different sizes, fitted together in uneven courses.

In San Antonio, the builders would probably have wanted to implement formal and technical solutions, adding windows to the perimetral walls, useful for internal lighting. Unfortunately, the lack of availability of a master builder in charge of Concepción resulted in downsizing the design aspirations and slowing down construction to the point that this was never completed (Felli et al. 2019). Father Morfi wrote: "La antigua Iglesia, se arruinò por ignorancia del Artifice. Se està construjendo en el mismo sitio otra nueva, que nunque no està concluida, pero va en buen estado, es capaz, sencilla, y de buen plan. En interin se oficia en la sacristia, que es un cuarto pequeño, pero muy decente y ascado con retablo nuevo dorado en que està colocado una hermosa Imagen de su Patrón San Antonio de Padua" (OFM, *Missioni*, M.88: *Memorias para la Historia de la Provincia de Texas*, 32*r*-32*v*, 1783).

For the construction of the new church of San José, skilled artisans, already active in other cities of New Spain, were presumably hired. This is suggested by the airy dimensions of the building, the controlled use of proportions, the slenderness of the wall structures and the rich sculptural decoration. Concerning the treatment of the rubble masonry (*mampostería*) walls, *rajuelas* are still visible, thus, small slivers of stone, inserted into the mortar joints, to fill and strengthen them as the mortar dried and hardened in order to minimize the mortar used (Giffords Fraser 2007, 102). The use of *rajuelas* manifests the adherence to the construction techniques of 17th and 18th century Viceroyal architecture: a *modus aedificandi* which in many regions of New Spain becomes the wall ornamentation.

San José also adopted an innovative use of structural barrel vaults, with the introduction of lunettes, allowing for open windows in the center of the bays: a technical solution already experimented, with less success, in the church of San Antonio. The refined sculptural decoration of the west elevation reveals a similar attention to details and helps in understanding some of the adopted design methods. If the plan was designed as a juxtaposition of autonomous elements, the façade appears to be composed both through juxtaposition and the overlapping of the various components in search of a unity typical of the European Baroque, far from the approach applied by the Franciscan missionaries in Sierra Gorda (Gustin 1969). An increasingly controlled design was associated with more complex construction practices in a noteworthy evolution for a context like that of Texas, broadly devoid of skilled artisans.

6 CONCLUSIONS

The Texas missions of San Antonio played a central role in the definition of a specific mission architecture in the 18th century. In a period of no more than fifty years and through continuous construction and social challenges, the missions resulted in a unique architecture, suitable for dealing with the extraordinary conditions of the northern frontier of New Spain. The adopted typological models and formal solutions were based on the interpretation of classical models from the Old World, originally reimagined to suit the religious, cultural and social life of indigenous people, with the creation of a spatial *continuum* from the outdoor to the interior sacred enclosure.

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History of Construction Cultures – Mascarenhas-Mateus & Paula Pires (eds)

The transfer of thin wood vaulting from France to America

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ABSTRACT: In the late 18th and early 19th centuries, the American republic searched for architectural expressions to convey its new-nation status and hoped-for permeance. At the same time, public funding for grand structures was limited, evidenced by the 14-year duration for the initial construction of the US Capitol (1793–1807). To help solve this problem, gentleman-architect and President Thomas Jefferson promoted a building technology that was at once cost-effective and suggestive of stateliness, namely Philibert Delorme's 16th century French framing technique. Jefferson was so effective in encouraging the method that architectural historian Doug Harnsberger has called Jefferson: "Delorme's fervent ambassador to America." This paper explores the transfer of Delorme's thin wood vaulting method from France to American in the 19th century.

> "Nothing is more simple than this structure and it is so cheap that it is used for barns in France. a very coarse & uninformed carpenter is making mine, who never heard of a dome before."
> Thomas Jefferson on Delorme's Method

1 INTRODUCTION

Thomas Jefferson first observed Philibert Delorme's structural method in 1786, humorously describing it as "a parcel of sticks and chips put together in pens." In many ways his description was not far from the truth; Delorme's 16th century framing technique allowed for wooden roofs to cover tremendous spans using individual pieces that were each only a few feet long. Delorme accomplished this by creating ribs of multiple laminations, specifying that breaks in each lamination did not line up with breaks on adjacent ones (Figure 1). The method of overlapping smaller wood sections to create laminated ribs allowed for the individual pieces to act compositely, structurally analogous to modern glue laminated beams, cross-laminated timbers, and even plywood.

The ribs themselves were stiffened by bracing them against one another using wood purlins at particular intervals. Once completed, a Delorme roof structure functioned as an overall system looking like a web of wood (Figure 2). But unlike modern laminated wood, Delorme's ribs relied on wedge shaped pegs and complex mortise-and-tenon joints rather than glue or other adhesives.

Delorme, who for a time was architect to the king of France, wrote his treatise during the French Renaissance of the 16th century. Examples of his framing method can be found throughout France and Germany though it was rarely used in civic or urban buildings owing to wood's inherent fire risk. Jefferson's encounter with Delorme's technique at the Halle au Blé in Paris was providential. He was in France as ambassador but had already begun to think about the architecture of the new American republic. The Delorme system allowed Jefferson a way to design and construct stately looking edifices without the construction complexity or cost implicit in brick and stone roofs.

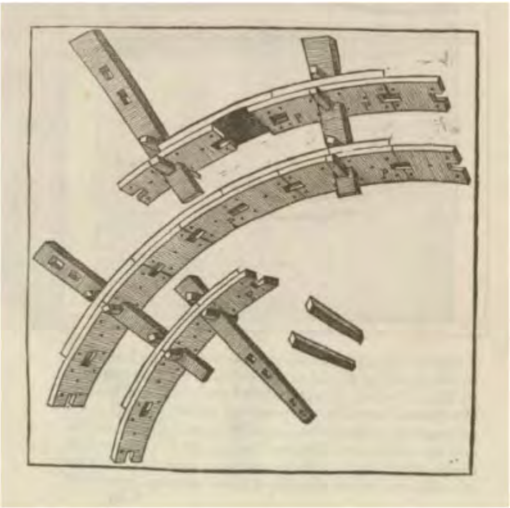
Figure 1. Rib lamination detail from Delorme's 1561 book *Nouvelles Inventions.*

To date, little has been published on Delorme's method in America. Blunt's 1958 biography on Delorme glosses over the framing technique almost completely, noting that *Nouvelles Inventions* contents are "mainly technical and throw little light … on de

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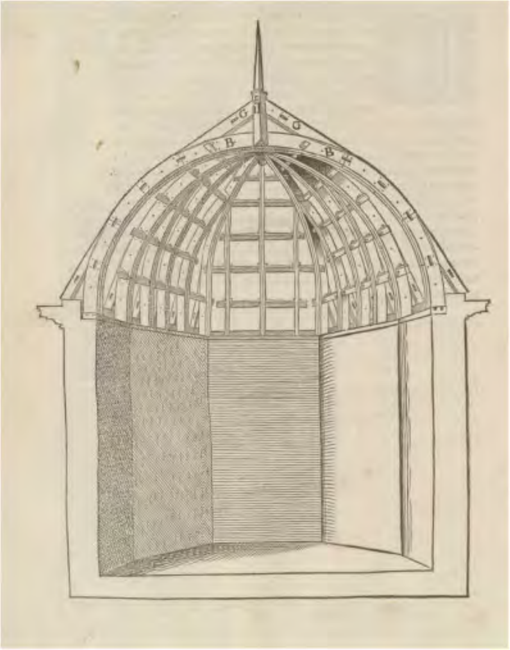


Figure 2. Section through a dome illustrating Delorme's method in his 1561 book *Nouvelles Inventions.*

l'Orme's conception of the art of architecture" (Blunt, 122–3). Most other articles cited herein contain only passing references to Delorme's framing and do not focus on its details or broader significance. Only Harnsberger, both in his 1981 thesis (which is not widely available) and also in his short but excellent article on Monticello, begins to address the details of Delorme's method in America. And almost nothing of substance has been written on the topic in the intervening 40 years since Harnsberger's work. This paper aims to present Delorme's story in America to a wider audience and point the way to possible avenues of future study.

2 ORIGINS

The origins of the thin wood framing method that came to characterize the domes and vaults of the early American republic can be found in the writings of the French Renaissance architect Philibert Delorme. Delorme was born in Lyon France in 1514 to a family of masons. In his late teens, Delorme travelled to Italy where for several years he studied the buildings of antiquity and worked in and around the Vatican. By 1536 he returned to France – this time to Paris – and began working on royal commissions. In 1548 Delorme was named architect of the king by the young Henry II. While in this role, Delorme designed one of his few extant buildings, the Chateau d'Anet in northern France. The chapel at the Chateau d'Anet, characterized by its stone-spiral coffered dome, evidences Delorme's status as "one of the most inventive minds to appear in French architecture in the 16th century" (Blunt, xiii) and "the first French mason to merit the title of architect" (Ballon 1989, 391).

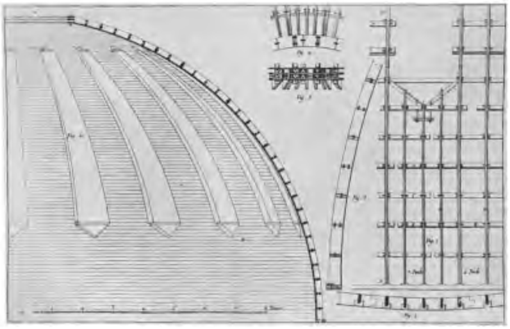


Figure 3. Details of Legrand and Molinos' 1782 Delorme Dome for the Halle au Blé, from Wiebenson, 268. The skylights can be seen in the elevation.

Delorme's status changed quickly with the sudden death of Henry II in 1559. Over the subsequent four years, Delorme devoted himself to architectural theory and writing, publishing his first work *Nouvelles Inventions* in 1561. It was in this book, later renumbered as books X and XI following his 1567 publication of *L'architecture de Philibert de L'Orme*, where Delorme's thin wood framing appeared (architectural historian Hilary Ballon claims the technique was the *Nouvelles Inventions* only invention!). The method, described above and rendered over many types of domes and vaults in the book's illustrations, was ostensibly in response to France's lack of large framing timbers available in the 16th century.

More than two centuries later, architects J.G. Legrand and J. Molinos resurrected Delorme's framing technique in their proposal to span the 120' diameter Paris grain market, the Halle au Blé. The Halle was completed in 1767 and stood for nearly 15 years without a roof. At least six proposals were submitted to span the building, including schemes of brick, stone, wrought-iron-and-glass and wood. Legrand and Molinos' wood framing method claimed Delorme's published technique for a domed cloister at the Abbey of Montmartre as their inspiration, noting that they were reviving his 16th century method. While it is questionable whether in fact Legrand and Molinos were the first to reuse the technique in late-18th century France, they did deviate dramatically from Delorme's method with their inclusion of some 25 skylights punctuating the dome (Figure 3). Because of the skylights, the dome suffered structural flaws almost immediately and the roof ultimately burned down in 1803 during periodic repairs to the copper roofing.

3 TRANSFER

It was during the 20-year life of the Legrand and Molinos' dome that Thomas Jefferson encountered the framing method. In August 1786, Jefferson visited the Halle au Blé with the English painters Richard and Maria Cosway, following an invitation from the American Revolutionary War painter John Trumball. Jefferson's impressions of the building and its dome are contained in his "head and heart" letter to Maria Cosway several months later (preserved today in the National Archives). In the letter, Jefferson struggles between his deep affection for Maria [his heart] and his admiration for the building itself [his head]. In one of the exchanges his *heart* confesses:

> "It was you [the head], remember, and not I [the heart], who desired the meeting at Legrand & Molinos. I never trouble myself with domes nor arches. The Halle aux bleds might have rotted down before I should have gone to see it. But you, forsooth, who are eternally getting us to sleep with your diagrams and crotchets, must go and examine this wonderful piece of architecture. *And when you had seen it, oh! it was the most superb thing on earth! What you had seen there was worth all you had yet seen in Paris!* I thought so too. But I meant it of the lady and gentleman to whom we had been presented, and not of a parcel of sticks and chips put together in pens. You then, Sir, and not I, have been the cause of the present distress."

Jefferson's heart, clearly sick from Maria's parting, was unimpressed by the dome. His head, unmoved, replies:

> "It would have been happy for you if my diagrams and crotchets had gotten you to sleep on that day, as you are pleased to say they eternally do. My visit to Legrand & Molinos had publick utility for its object. A market is to be built in Richmond. What a commodious plan is that of Legrand & Molinos: especially if we put on it the noble dome of the Halle aux bleds. If such a bridge as they shewed us can be thrown across the Schuylkill at Philadelphia, the floating bridges taken up, and the navigation of that river opened, what a copious resource will be added, of wood and provisions, to warm and feed the poor of that city. While I was occupied with these objects, you were dilating with your new acquaintances, and contriving how to prevent a separation from them …"

Much ink has been spilled as to how much Jefferson's admiration for the Delorme method owed to his acquaintances, particularly Maria, that day. History records that Jefferson and Maria Cosway never met again after she returned to England and he returned to the United States in 1789. Just prior to leaving France Jefferson acquired a copy of Delorme's treatise, possibly indicating his desire to use the method when renovating his home at Monticello. Alternately, he may have already had broader goals for the technique. Whatever his original impulse for purchasing the book, throughout the subsequent three decades Jefferson would not only promote the "parcel of sticks and chips" in his own designs, but he would convince many of America's earliest architects to employ Delorme's method over many of the grandest buildings in the young nation.

4 PROLIFERATION

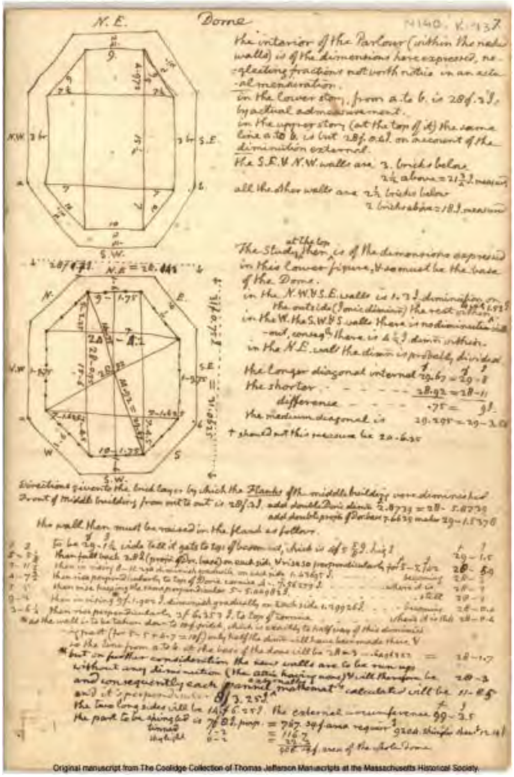
The first examples of Delorme's method in America exist only on paper. In 1792, Jefferson submitted a proposal for the President's House as well as a circular plan for the US Capitol. Each design presumed a Delorme-framed roof. Jefferson's President's House entry – loosely derived from Andrea Palladio's *Villa Rotunda* in both plan and elevation – contains a drawing illustrating the glass skylights of the Halle au Blé articulated within the dome. While neither proposal was accepted for the early federal buildings in the nascent city of Washington, Jefferson's use of the circular form for the Capitol building and a domed roof at the President's House suggest that he and others were looking for an architectural style that implied both permanence and stateliness.

Toward the end of his term as John Adams' vice president, Jefferson's carpenters completed the octagonal dome above his home at Monticello (around 1800). This was one of the earliest, if not the earliest, Delorme structures in America. Owing to the irregular geometry of the space it surmounted, the notes for the dome contain both sketches and equations where Jefferson attempted to calculate the amount of material he would need (Figure 4). Shortly thereafter, he sent plans and a detailed description to an anonymous friend who described the technique in greater detail:

> "the ribs (or rafters) are made of oak plank one inch thick, 13 1/2 I. wide, & cut into lengths of about 4.f. four thicknesses are put together mitered together at their ends according to the curve & breaking joints so that no two joints come together. they are nailed together with half crown nails, going through and clinched. when set up, they are honeycombed by short pieces put in cross wise from rafter to rafter …"

The description shows how Jefferson adapted Delorme's technique in the American context. While the court carpenters of France could easily have followed Delorme's mortise and tenon details for the ribs and purlins, fewer carpenters in the United States would be competent with these joinery methods. Jefferson's use of nails, which his plantation had begun to manufacture around 1794, allowed him to greatly simplify the connection of the laminations as well as of the cleats and purlins to the ribs themselves.

Many Delorme structures followed rapidly in the footsteps of Monticello. The young architect Robert Mills visited Monticello during the octagonal dome's construction. While there he closely observed and sketched the details of its construction. Meanwhile, Jefferson's ascension to the American presidency in 1801 set the stage for the wider adoption of the method



Original manuscript from The Coolidge Collection of Thomas Jefferson Manuscripts at the Massachusetts Historical Society.

Figure 4. Framing plan and notes from Thomas Jefferson's 1794 Remodeling Notebook showing his analysis of the octagonal room's Delorme dome (source: Fiske Kimball's book *Thomas Jefferson Architect*).

Figure 5. Baltimore Cathedral watercolor by Benjamin Henry Latrobe (1818?). Maryland Historical Society.

by another of its early adopters, Benjamin Henry Latrobe.

Like Jefferson, Robert Mills' first Delorme proposal for a *Rotunda House* was on paper only (1803). Subsequent to that, Mills embarked on the design and construction of a series of five circular churches in Charlestown South Carolina (1804, burned 1861), Philadelphia (1808, demolished?), Richmond (1812), Philadelphia (1813), and Baltimore (1816). During much of this same time, Jefferson was in Washington persuading the British architectural émigré Benjamin Henry Latrobe to employ Delorme's method in federal buildings. Jefferson first suggested the technique to Latrobe in a submission for the Navy Drydock (1802 – unbuilt). Then, following Latrobe's appointment to Architect of the Capitol, Jefferson's influence led to the successful construction of a Delorme dome over the Hall of Representatives at the US Capitol, this time complete with Hall au Blé skylights (1805, burned 1814). It is well known that Latrobe argued, unsuccessfully against Jefferson, for a dome of more permanent materials and with less direct glazing than the skylights at the Halle au Blé. His concerns were well placed. Shortly after the House of Representatives was occupied most of its skylights were covered on account of both sun and rain. And in less than a decade, Jefferson's beloved Delorme roof burned at the hands of the British in 1814.

Latrobe was sufficiently convinced of the utility of Delorme's method, however, that he employed it on many occasions after the US Capitol project. Within a year of the Capitol's completion, Latrobe used Delorme's method at the University of Pennsylvania (1806, demolished 1829). He later employed it at St John's Church in Washington (1817), at the Baltimore Exchange (1817, demolished 1907?) and in his hybrid brick-and-Delorme dome at the Baltimore Cathedral (1817, Figure 5). At the Baltimore Cathedral Latrobe achieved his desire for the more technically demanding but permanent masonry inner dome, complete with a single oculus. However, he chose to cover his masonry dome with a ribbed Delorme outer structure containing 24 radiating skylights. This allowed him to control the light in an indirect manner, filtering rather than flooding the floor below. In doing so, Latrobe solved many of the problems inherent in the US Capitol dome a decade earlier.

Beginning in the second decade of the 19th century, other architects with less direct relationships to Jefferson constructed monumental buildings using Delorme's technique. Robert Cary Long designed and built the medical school Davidge Hall at the University of Maryland in 1812. Harnsberger proposed the several possibilities by which Long may have become familiar with Delorme's method, though no definitive connection to Jefferson, Mills, or Latrobe has been established. Another Delorme structure over a medical building appears to have even been constructed (with skylights) at Harvard Medical School by a certain Jacob Guild (1816, demolished 1860?). French architect Maximilian Godefroy's Richmond City Hall (1816) and Baltimore Unitarian Church (1817) have likely but ultimately unclear design connection to Robert Mills and Benjamin Henry Latrobe respectively. However, as a native Frenchman Godefroy's familiarity with the method may likely come from his homeland. And connections to both Mills and Latrobe almost certainly resulted in Alexander Parris'

Figure 6. Delorme framing plan for the Rotunda at the University of Virginia drawn when Jefferson was in his upper 70s. The density of linework in the lower right corner of the image is indicative of the sub-ribs required on lower levels of the dome.

use of Delorme framing at the Massachusetts General Hospital (1823) and Quincy Market (1825).

Perhaps the most well documented Delorme structure – in terms of extant drawings and written description – is Jefferson's final design for the dome of the Rotunda at the University of Virginia (UVA 1819, burned 1895). Constructed during the eighth decade of his life, the Rotunda literally wove together many of Jefferson's wide-ranging ideas about architecture, education, and the body politic (Figure 6). Curiously for a building over which Jefferson wielded near complete design control, the Rotunda did not contain Halle au Blé skylights. This likely owed to his desire for the dome's interior surface to be used as a representation of the night sky. Unfortunately, and as with many of Delorme's American descendants, the UVA Rotunda's dome burned in a spectacular fire in 1895. Its destruction made way for another technology that had recently crossed the Atlantic, the Spanish tile domes constructed by the Guastavinos, to surmount the original Jeffersonian walls.

Nineteenth century Delorme structures continue to be identified. A small, presently undated garden pavilion at James Madison's Montpelier – less than 30 miles from Monticello – contains a Delorme dome as evidenced by its recent roof replacement. The Exchange Building in Petersburg Virginia, designed in 1841 by a largely unknown architect named Berrien, has also tentatively been identified as having a Delorme dome. Others will doubtlessly continue to emerge as preservation efforts uncover the structures beneath roofs of both humble and high-design buildings.

5 CONCLUSION

This paper, including and especially its title, echoes George Collins' 1968 article "The Transfer of Thin Masonry Vaulting from Spain to America" in the *Journal of the Society of Architectural Historians.* That piece, written in the shadow of the "modern concrete shell" looked at concrete's thin masonry precedent and the transfer of the masonry-tile technology from Spain to America by way of the Guastavino family. Collins' article was a seminal piece – outlining the material, methods, origins, transfer, and proliferation of tile vaulting in America – and it set the stage for a tremendous amount of subsequent work that continues today.

In the time I have studied Jefferson's use of Delorme's method at the University of Virginia, I have begun to see a similar transfer of a structural vaulting technology occurring a century earlier. Several historians cited herein have touched on many aspects of the Delorme system. But no comprehensive study exists that is comparable to Collins' treatment of the thin masonry vault. And at less than one quarter the length of Collins' 1968 article, this paper only begins to chart an outline of such a study. The next few sentences also point to opportunities for future research. (1) Analysis of the Delorme method as a structural system is virtually non-existent. Delorme claimed his method could span more than 300 feet! How he arrived at such a number is unknown. The Halle au Blé, one of the largest Delorme domes built, was notably unstable at 120 feet (likely on account of its skylights). To my knowledge no rigorous structural analysis has been performed on any example of the system. (2) Guastavino structures were famously resistant to fire. By contrast, Delorme structures are famously prone to destruction by fire. Methods of fire protection for the remaining monumental Delorme structures is a topic worthy of preservation research and practice. (3) Finally, Collins' article and the more recent book on the Guastavinos by John Ochsendorf has led to many monographs and papers on individual Guastavino buildings. There likewise exists an opportunity for not only a longer article (like Collins' work), but probably a book-length study of Delorme in America. The many question marks noted in the dates of the previous section (i.e. "demolished 1907?") point to the need for more historical research on each of the buildings identified thus far.

While Delorme structures never became ubiquitous enough to be used for barns in America (as Jefferson claimed they were in France), the two dozen buildings described above speak to the impact Delorme's method had on American political, ecclesial, and collegiate architecture. Were it not for the relatively inexpensive and yet expansive structures afforded by Delorme's method, America's early monumental architecture may have looked very different.

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History of Construction Cultures – Mascarenhas-Mateus & Paula Pires (eds)

Tradition and invention in domestic construction in the Caribbean region: The case of Southern Puerto Rico

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ABSTRACT: In most Caribbean countries the historic habitat expressed the culture of dominant and subordinate groups. In house form this has evolved into two referents, the grand houses and the small huts of the dispossessed. In southern Puerto Rico, the *casa criolla* and the *casita* fit this scheme. Both dwelling types, keeping social traditions of the past, have however been reinvented and improved for over a century, showing evolving responses to climatic and social imperatives. The *casa criolla* became a sophisticated socio-climatic artifact while its poor cousin, the *casita*, flexibly responded to proletarians' need for simple, basic and functional – frequently movable – shelter. The tension between both house types spread over the agricultural and mercantile landscape following the evolution of a maturing society and economy. Though both types are threatened and no longer constructed, their physical and cultural presence is still a constant.

1 INTRODUCTION

The insular region situated between both American continents – the Caribbean and Bahamian archipelagos – was the first sustained point of contact between European explorers/colonizers and the native Amerindian peoples then residing. From the end of the 15th century, these islands were veritable experimental grounds for new modes of culture. More than four European nations established new sociopolitical and economic entities accompanied by widespread demographic changes. These islands became a microcosm for European rivalries (Williams 1970).

The Spanish islands, though, evolved into military outposts with scarcely developed hinterlands as focus shifted to the wealthier domains in present-day Mexico, Peru, and other continental places. Not until the end of the viceroyalties in the early 19th century would there be interest on the productive assets of the remaining colonies of Cuba and Puerto Rico (and the remote Philippines).

Up to then, Puerto Rico's southern part, separated from the fortified capital of San Juan by a barrier of mountains in some places rising to over 1300 meters altitude, had been an economic backwater, mostly inhabited by small-to-medium-scale farmers. Many of these took advantage of the numerous inlets and bays of the coast for legal and illegal trading in different products (ginger and hides were a popular export in the 17th century). Though some sugar production always existed, most of the population lived on small to medium holdings called *estancias* located on usufructs carved from Crown lands. Most of them concentrated near the few existing towns such as San Germán, Ponce and Coamo. These towns, according to a chronicler, were sort of "market towns" which were populated mostly over the weekend, with small houses flanking a public square where the church and *casa del rey* ("king's house", where any existing instance of government would be housed) were the two major institutions.

2 PEASANT AND TOWN HOUSES IN THE EARLY PERIOD

The typical peasant house was essentially of a rectangular plan: one or two rooms, gable roof, usually clad with rustic planks or leaves, placed on top of a wooden platform with six or eight rustic trunks as supports (Abbad 2002 [1788]). The chronicler Íñigo Abbad y Lasierra referred to them as "adequate for the climate and circumstances of the country" (*ibid*.). Because of the dearth of level terrain, artificial platforms became,

Figure 1. An *estanciero* house in San Germán, Puerto Rico. Possibly late 18th century; lost in fire ca. 2000 (photo by author, also reproduced in Jopling, 1988).

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early on, an obligatory feature of vernacular dwellings. The elevation offered by these platforms also had collateral benefits of separating the house from the soil, giving protection against damp and vermin. These would make the elevated platform a practically universal component of Puerto Rican domestic buildings, in city and country, slopes and flatlands, wealthy or humble homes.

A probable late 18th century *estanciero* house (estimated ca. 1780–90) south of San Germán, documented by this author in 1979 (also seen in Jopling 1988), was constructed on this platform concept. In this case it was clad with native wood planks and roofed with a two-slope pyramidal wooden roof covered with half-round "Spanish type" tiles (the outer slope was shallower). The planking was set tight and apparently caulked with natural resin in such a way that the wall gave a nearly continuous finish. The level of sophistication of the joints of the roof at the meeting of the vertical support posts, as well as where the rafters meet on the roof's apex, demonstrates a very precise fit and dexterity in the cutting of mortises and tenons. A short block of wood acting as a small ridge stabilizes the whole assembly.

The division between the rooms had a curious painting, rendered in lampblack, with a "sun" and silhouetted "knight" figures on either side. To "bless" the home, a cross was placed on or near the center of the house, in this case on the inner partition separating the two original rooms. It could also be on top of the roof, as seen in a conjectural drawing of another *estanciero* house shown by Salvador Brau (1904, 28). Both the house visited in 1979 and the one drawn in the Brau book show the use of high-sill windows. They were closed with planked single or double panels.

The next important evidence was a house presented in a painting done in 1785 by Puerto Rican artist José Campeche, *Dama a caballo* (Lady on a Horse). On the right of the background, a diminutive representation of a house can be seen with an adjacent conical-roof structure. The cone-roofed building was surely a trapiche or oxen-powered sugar mill, but the house – surely the estate house associated with the mill – catches the most attention.

Though not, in most likelihood, sited in the southern coast area (Campeche had his atelier in San Juan), the house already shows several characteristics seen in many estate houses built in the next century: beside the use of the platform on stilts and hip roof, there was the use of extensive veranda-type balconies and a rear utilitarian extension habitually known as the *martillo* or "hammer", functionally and physically similar to the ell seen in parts of North America. This segregation by volume and function would improve the performance of the *casa criolla*, a spatial distribution developed by the 1830s.

The next graphic evidence found are the sketches of towns made by the French naturalist Auguste Plée (1786–1825) (Alegría 1974; Thésée 1989). Though they were quite crude, possibly to be refined upon Plée's return to France – which never materialized as he died before attempting to return – some of them are quite explicit in revealing urban and dwelling general form in the early 19th century. These drawings were realized in 1822 or 1823 and they reflect a decisive moment in Puerto Rican history: the takeoff of the new economic reforms facilitated by a Royal Decree of Grace (*Cédula de Gracias*) promulgated on 10 August 1815 (Rosario 1995).

This decree offered free land and tax incentives to qualified agricultural investors who promised to farm major cash crops – sugarcane and coffee – for export. Hundreds of these investors, including Europeans and wealthy residents of the former American viceroyalties, all fleeing turmoil back home, availed themselves of this program. Southern Puerto Rico showed considerable growth because of availability of good fertile land and ease of exporting through many well-placed bays and inlets. Later in the century other agricultural capitalists joined them, these from several Lesser Antillean islands where slaves were emancipated in 1848; they came in – sometimes with their slaves – to enjoy the perceived benefits of this system of servitude for a quarter century more, as it was not abolished in Puerto Rico until 1873 (Scarano 1993; Figueroa 2006).

The habitat set up by these migrant groups was largely defined by a more evident *creolity*, more so than the languages of their habitats of origin. This building creolity came out of the need to adapt lifestyles of migrant groups that repopulated the Caribbean islands after the decimation of the original Amerindians and the quite abrupt disappearance of their more overt cultural practices, which included particular ways of configuring the habitat. The new plantation or mining economies, settled on territories with new situations of climate and available, sourceable materials, and bringing together humans with diverging cultural traits, forced a culture of transaction, with a particular and definite habitat expression. Though Caribbean creole architecture's visuality has been frequently romanticized (Cliff, Slesin et al. 1998)

Figure 2. The town of Patillas in south-eastern Puerto Rico. Drawing by Auguste Plée, 1822. (Muséum d'Histoire Naturelle, Paris).

not much about its development has been analyzed, barring studies like those of Berthelot and Gaumé (2002). These authors developed a two-tiered explanation of traditional Caribbean domestic architecture (the grand or estate house, and the hut or *case*) that serves as a basic explanation applicable to Puerto Rico. Some of the Plée drawings in Puerto Rico hint at the maturation of this new building culture. Three south-eastern settlements show this quite eloquently.

The most revealing is the drawing of Patillas where a gable-roofed house appears under construction with a building brigade visible inside it. The trusses are very clear though not details of their framing. It is also evident that the side of the truss facing the viewer has two slopes or a slightly curving one, with the flatter slope or part on the outside. Though not conclusive in this case, it could be that the slope change may signal the presence of the balcony or veranda. The house overall shows a post-and-beam structure for floors and walls, and no partitions seem to be in place yet. The framing solution is similar to the still-extant ca. 1860's great house of the Alomar estate in Santa Isabel, further to the west, which has been identified as a post-and-beam "box" with hip roof superimposed. It has shown excellent resistance to climate and the passage of time; in fact, it survived Hurricane Maria of 2017.

The Patillas house drawn by Plée also has a *martillo* though it does not seem to be structurally integrated into the main house. The separation may be due to social segregation or, conversely, to avoid the structures of it and the main house interacting adversely by the effect of natural phenomena. In later examples, especially after the flowering of the *casa criolla*, the *martillo* would be structurally integrated to the point of structural continuity in walls and roof.

In the other two towns of the region where houses were drawn in some detail by Plée – Guayama and Maunabo – the larger houses have a steep hip roof which, according to the drawing, seems to be of thatch. Thatch with leaves from the *enea* or cattail grass (*Typha latifolia*) was a very common roof cladding possibly from pre-contact times to the mid-20th century, and in the early 19th century it was the most sourceable roof cladding material.

Figure 3. The Alomar estate house (ca. 1870) in Santa Isabel, Puerto Rico in its present condition (photo by author).

Also in the drawings, much less detailed save for their volume, the smaller huts or *casitas* can be frequently seen, usually distinguishing themselves by their smaller scale and the high frequency of gable roofs. Gable roofs are easier to build as they do not require the relatively complex "calculations" of joining four slopes together to build a hip. Both types would coexist in the remainder of the century, with gable roofs being more frequent with the passing of time.

Many *casitas* would adopt the technology of the grass-clad hut or *bohío*. Many *bohíos* would forsake the raised platform, using instead the dirt floor and adopting hammocks (*hamacas*, a word taken from the Taínos) as a hygienic solution for sleeping. A tendency of spatial segregation at the urban scale was seen in the growing towns and cities during the 1800s: the larger dwellings, mostly *casas criollas*, near the center and a periphery of *casitas* for the proletarians, artisans and service workers.

3 THE EVOLVED CASA CRIOLLA

By the 1880s the specific form of both house types consolidated, and some examples have survived to our present time. The southern portion of Puerto Rico, close to the Caribbean Sea has retained many examples, some of them protected by preservation regulations, especially in the larger towns like Coamo, Guayama, Ponce and Yauco. Also common are estate houses on cane, cattle and coffee farms.

The *casa criolla* will be considered. Among the possible forebears of this type of house, there were the Central Spanish bourgeois houses. The residential component of Ponce de León's house in Caparra, the first Spanish settlement in Puerto Rico (1508–21) was of this type, as well as the Alcázar de Colón in Santo Domingo. It is also believed that the usually center-located hall of houses in many European countries expanded into a full living space; and the "dogtrots" of some areas of the Gulf of Mexico coast of the United States of America – country that had considerable trade links with Puerto Rico then – may have had significant influence (Ortiz Colom 2017). In any case, the form of upper-class housing in Puerto Rico departed from peninsular Spanish tradition. In fact, the *casa criolla* is more related to similar houses in Caribbean islands and continental coastal regions, including places of non-Spanish colonial presence.

The *casa criolla* in Puerto Rico eventually was rendered in a variety of materials, including wood, *mampostería* (rubble masonry), brick and even concrete in its later iterations in the first third of the 20th century. Most hard materials and wood frames are locally sourced, though cladding and roofing may be imported components. The stylistic expression has also had some variation, but it was codified into its own

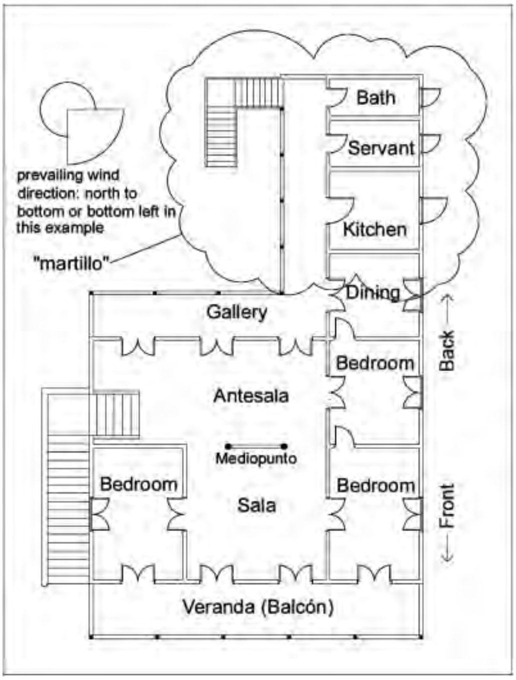

Figure 4. Generic diagram of a typical Puerto Rican casa criolla. The version shown would be a second storey over a commercial ground floor (Drawing by author).

structural and spatial relationships. The basic diagram is composed of two rectangles, one for the main part of the house (living and bedroom space for the "owners") and the *martillo* with its service spaces, forming together an "L"-shaped plan. The L is oriented in such a way that the two "wings" of the house plan form a wind scoop that catches the usually eastern breeze. The evolved form of the *casa* commonly found in southern Puerto Rico requires further explanation, which follows.

The main rectangle, raised on posts, columns, or a commercial/warehouse ground floor, is divided into three zones – a center living space flanked on either side by bedrooms (on situations where the house is narrow, one bedroom zone may be suppressed). *Casas criollas* usually have a full veranda in front with several sets of double doors opening from the inside, both the living space and the front bedrooms. As observed, these central spaces in urban houses can range from 5 to 7 m wide and the bedrooms from 3 to 5 m on each side; this means that these houses – if they have rooms on both sides – can vary from 11 to 15 meters in width, which helps them fit into relatively narrow urban lots. The main volume is generally two spaces deep – from 8 to nearly 12 meters in most cases. This modular conception of space (Jopling 1988) gives the *casa criolla* considerable flexibility: in fact, when they were abandoned as residences beginning in the 1950s, many obtained a new lease in life with office, institutional and even commercial uses.

Figure 5. A mediopunto partition inside a former casa criolla living space converted into offices, Aibonito (photo by author).

The living space is the largest and most noticeable spatiality in *casas criollas*. To divide this space, which can attain generous proportions and quite ample scale, a half-structural, half-decorative partition called the *mediopunto* (midpoint) was placed in the middle, creating two functional zones: the *sala* or more formal living room towards the front – where visitors were routinely received – and the *antesala* or "anteroom", paradoxically placed towards the rear and which was more reserved for the family – a sort of early iteration of the "family room" usually seen in modern domestic layouts. The *mediopunto* frequently was an ornate, sculptural job composed of different lathed, jigsawed or finely-cut parts of wood with occasional elements in plaster or metal, and sometimes it would incorporate storage cabinets.

This *mediopunto* created spatial complexity and richness in the center of the common domain of the houses, only comparable with work in parts of the doors and transoms, and of course, the balconies. Other decorative textures like stenciling, multi-color hydraulic cement tiles (called *losa criolla*) and plaster ceiling rosettes would also "enrich" the visual texture of space (Rigau 1992).

The front verandas merit some discussion. Usually lifted on a high, enclosed base of hard material in urban contexts, this element acquired a definite spatial personality and livability because of its relatively ample dimension (at least 1.5 m, sometimes growing to as much as 3 m).

This space, known as *balcón* ("balcony") in Spanish, is not so much a lookout like the balconies common in most countries of the Mediterranean basin, but rather a covered veranda that can be used as a living and social space (Quiles 2009). Of probable Hindustani origin, brought to the Caribbean by the British, and reinforced by similar African influences, the *balcón* can fit seats, hammocks, tables and other domestic furnishings and is quite ample for receiving and socializing with outsiders.

The *balcón* also works climatically to reduce solar load on the walls and as a sort of windbreaker to reduce

Figure 6. A 19th-century casa criolla in the center of Guayama showing balcony (photo by author).

impact on the walls behind it. A well-built *balcón* can also help strengthen the outer wall assembly. Many *balcones*, in the early 20th century, were rebuilt in reinforced concrete while keeping the wooden main structure, creating another level of visual complexity and interest in the process. These more rigid balconies in fact have created a degree of continuity in the transformation of buildings in neighborhoods, when the wooden structures were dismantled because of deterioration and frequently substituted with reinforced concrete walls and flat roofs. At least the concrete latter-generation *balcones* have survived, keeping a visual relation with the past alive.

The *casa criolla* has a tendency to use high ceilings in the four to five meter range (sometimes even higher), improving the exchange of heat from the lower portion of the rooms as hot air can ascend more easily and is swept away by ventilating openings like door transoms and ceiling grillwork. Many windows evolved from relatively small high-silled openings to a larger void known as the *antepecho*, basically an inward-opening two-paned door with a fixed railing for safety. This way, air movement could be increased from the outside. Doors were double-pane, and they had a glass pane on the top, and just below it an operable-jalousie panel that could be manipulated for permitting ventilation with a closed door. These doors were a very sophisticated device for controlling air, light and privacy. Many transoms – rendered in different combinations of wood, glass, and metals – could also be operable.

A final consideration of the *casa criolla* is the major role of many roofs. Gable and hip roofs became massive volumes, housing large insulating airspaces, sometimes attics. In many of them the art of the carpenter approximates that of experimented boatbuilders. The best examples show an extensive, possibly redundant use of triangulation and bracing in different directions. An extant example from Arroyo (south-east) shows this reinforcement with diagonal braces in different directions. This roof, in fact, perfectly resisted the strong Hurricane Maria of September 2017. There also exist single-pitch roofs behind parapets, mostly as a later evolution in houses with hard-material outer walls. These examples keep the traditional inner spatiality.

Figure 7. Structure of the hip roof of the Riefkohl-Manautou house in Arroyo (photo by author).

Usually, the best woods were dedicated to framing the roof and wall posts/beams, such as ausubo or balata (*Manilkara bidentata*), moralón (*Coccoloba pubescens*), ortegón (*Coccoloba rugosa*), higüerillo (*Vitex divaricata*) and several others (Little & Wadsworth 1964). These woods were acclimated to the lush tropical forests of the interior, and were resinous with an innate termite resistance, unlike imported pine that was used from the mid-19th century. Usually roofs were pegged together. Long pieces were obtained usually by using keyed, pegged scarf joints usually called in Spanish “*rayo de Júpiter*” (Jupiter’s [lightning] bolt). They are common on the top beams of walls and on bottom chords of trusses. Structurally, the roof was used to fix the “boxes” formed by diagonally braced external walls and floors. Internal walls had a secondary supporting function; they acted as diaphragms to stiffen the box and reduce stresses on joints. These walls generally were constructed as membranes with smaller or flatter profiles in the studs while the outer walls were defined by the larger posts and braces. Horizontal diagonal bracing in the ceiling plane was also frequent.

Roof cladding varied during the evolution of the *casa*. Early versions used either shingles (in many cases imported from North America) or half-round Spanish-type tiles placed over very closely-spaced purlins. Later, corrugated iron – developed in Britain in the mid-19th century – became immensely popular and was used as a roof cladding from the 1870s. As previously mentioned, there was a gradual tendency to use side-gable roofs (i.e. the roof slopes toward the front and back and the ridge in parallel to the front; the gable ends are towards the sides and normally have ventilating grilles of wood slats). The more common roof truss type was of the king-post type with additional diagonal bracing reaching out from the union of bottom chord and post to the middle of each rafter (top chord). Little variation is seen in this truss configuration. Though this roof geometry increased wind vulnerability, its ease of building and maintenance made it the most popular alternative in the late phase of the *casa*.

The *martillo* or ell was of simpler construction, almost invariably gabled and less common single-sloped; but it was essential in the more mature form of the *casa* to structurally tie it with the main volume. This required well-placed transitions at the point of intersection of both roofs. Since this part of the house was only a room deep – with an aisle or gallery on the patio side – and much narrower – it was subject to less structural stresses, thus behaving as a structural appendix and frequently as a sacrificial element to the larger house in case of hurricanes. In a few cases these *martillos* have been eliminated and substituted with a full-width extension with a less steep continuation of the house's main roof.

The *casa criolla* was a largely self-contained entity, that was not very amenable to modification or extension, though in some houses lean-to extensions were attempted on the gable end sides or the back; these generally could not be integrated structurally with success to the larger house. It has also had an important symbolic and iconic value seen in works of literature and art (Laguerre 1938; Marqués 1968).

4 THE CASITA

The *casita* was the *casa criolla*'s diminutive counterpart. As a lightweight, square or rectangular box with a dimension averaging in some cases as little as three meters on each side and possibly reaching in plan up to some 5 × 10 or 6 × 6 meters (larger examples are seldom seen), it was the habitat of peasants and peons. Besides the much smaller size it served a different function: it was the abode for intimacy and sleeping. Most of life was experienced outdoors and an easy and cheap solution for an improvised "living room" was to condition and sweep the small yard in front of the house, improvise some seating (even with trunks and rocks) to form what has been called the *batey* (from a word of the Taíno Amerindians that originally described a ceremonial ballgame, later extended to its venue and, by extension, to outdoor spaces used for congregation).

The house, raised on stilts, was not visited by nonresidents. Neither were hygienic activities or cooking realized in most of these houses: separate small pavilions were usually built for these uses. In many of these houses a storm shelter or *tormentera* would also exist, a triangular prism close to the earth, of relatively small size (2×3 to about 3×5 meters), which relied on its relative aerodynamic resistance to house the families during strong winds.

Figure 8. Casita near the public square of Juana Díaz, Puerto Rico (photo by author).

Since the tropical climate was sufficiently benign for outdoor living, the *casita* did not have much spatial differentiation (Rodríguez 2017). It would have one, two, sometimes three rooms in the main volume. Generally, the material was wood, finished or rustic, for building the frame. Poorer-quality varieties of wood were used in the *casitas* in towns or plantation estates; in the countryside better trees could be felled and roughly dressed. Cladding could be wood, thatch or palm leaf or frond on walls; roofs were thatched with *enea* (cattail) grass, shingles, or corrugated iron (usually previously used). An outgrowth of the *casita* was the typical early-20th century slum house, in which discards of the urban economy like cardboard, flattened biscuit tins, signboards, and the like were put in service to clad walls and give privacy, substituting unavailable natural materials. Many slum houses were built out in swampy channels on platforms over the water.

Detailing of the *casitas* was minimal, they were above all utilitarian shelters with minimal functionality. Their handling of climate was relatively poor, lacking nearly all the devices used in the *casa criolla*, and they did not resist extreme wind or rain events.

They were short-life abodes (less than 20 years), but most had the advantage of being transportable on carts, trucks, and the lighter ones by sheer muscle power. This was a necessity as most *casita* dwellers were landless, and they squatted legally as *agregados* (sharecroppers) on large farms, or illegally on disputed lands near or next to towns.

Though some had more complex hip roofs, nearly all *casitas* were gable- or shed-roofed. If they used gables, in most cases only the top chords and the ridge beam were installed; spans were so short that the bottom chord and the diagonal braces made little sense. Slopes were low-angled to save some roofing material.

It was usual to grow the *casitas* by aggregation of shed-roof lean-tos, which sometimes could envelope most façades of the original house. Some *casitas* were

Figure 9. Interior of a casita in Planadas, an abandoned settlement in Cayey, Puerto Rico. Notice the elementariness of framing (photo by author).

supplemented by mini-verandas in imitation of those of the *casa criolla*.

Outside from barrack-type buildings usually rented by the room or even by the bed in cities and some agricultural estates, the *casita*, its poorer cousin the *bohío*, and their ilk were the solution for many decades for low-income housing in Puerto Rico and the Caribbean. Unlike the *cases*, chattel houses and other similar structures in other islands, *casitas* did not evolve into more ample or complex dwelling types.

Sometimes, *casitas* were built as residences for house-servants in more substantial properties. They were of the same type as resident-owned *casitas*.

5 CONCLUSIONS

From the 1930s, alternate house types and programs, specially the *Siedlung*-influenced *caseríos* or public apartment buildings, threw many Puerto Ricans into a different culture of habitat. In the countryside, many *casitas* and all *bohíos* disappeared in a generation and squat, square flat-roofed houses with a more "modern" American suburban-influenced layout became the norm for country residents. Many peasants became sessile pseudo-yeomen as they were assigned relatively small allotments or *parcelas* on 1000 to 2000 square meters of land, and employment in urban commerce, industry or government substituted old farming subsistence. A few *casitas* survive for some of the more modest families.

The two dwelling types described here have resulted from a long heuristic process. The *casa criolla*, a product of tenacious experimenting with tropical life in a rural and merchant society; summing up a combination of principles that were derived anonymously by continuous trial and error, and adaptation to specific forms of nature and climate, different from those of their ancestors' countries of origin. In this dialectical process, new building forms differentiated from the ancestral ones were spawned. As no continuity with the longer-established Amerindian settlers existed because of the severe cultural dislocation of these habitants in the 16th century, previous lessons from the Taínos – outside of the available palette of materials – could not be known. Taíno dwelling forms have been painstakingly reconstructed with the tools of archaeology; their houses were quite distinct from the stereotypes of the round or polygonal little *bohío* popularized by Spanish chronicler Gonzalo Fernández de Oviedo and others after him.

The *casa criolla* could derive its configuration from a relatively ample choice of mostly local materials as well as social, cultural, aesthetic and climatic considerations; while the *casita* was shaped by need, poverty, resource limitations and the expediency of survival. For several generations from the early 19th to middle 20th century, both dwelling types coexisted in a sense symbiotically, expressing social and class divisions in the habitat. The disruptive clash of modernity aborted the evolution of these dwelling types in such a way that three-quarters of a century later Puerto Rican architects and planners are still fighting with the ghosts of these old dwelling forms, which form a referent critical of the still hegemonic International-Style formal and technical vocabularies and patterns. The Puerto Rican contemporary architectural scene is not unlike other Global Southern countries that are torn between their fragmented past and their uncertain future.

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History of Construction Cultures – Mascarenhas-Mateus & Paula Pires (eds)

Translating the "Chinese roof": Construction culture hybridization in West China Union University

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ABSTRACT: Discussions of technology initiatives in architectural design and adaptive thinking in Christian universities in modern China are as yet insufficient. This study focuses on "translation" during the Sinicization process in the architecture of Christian universities in China in the early 20th century. With evidence from West China Union University, it conducts a retrospective analysis of the process, methods and results of the campus planning and architectural design in which Western architects were involved. Taking a closer look into aspects such as material selection, structure, construction, decoration and craftsmanship, it is borne out from the perspective of engineering that it is possible to translate "Chinese roof" mainly based on the Western masonry structure, but it also involves many challenges – it is the thinking and experiments of Western architects to solve such challenges that may contribute to the interesting change of construction cultures from hybridization to integration.

1 INTRODUCTION

The role and influence of the Western Christian world on the process of China's modernization has long been in focus in academic circles (Fu & Xiao 2012; Wu 2017). Due to ideological and geopolitical reasons, comprehensive observation and fair evaluation to evaluate the important role and historic influence of Christian universities has been a difficult task so far: it was harshly and blindly criticized in early stage; widely and highly praised later on (Zhao 2017). There is no denying that Christian universities inevitably became instruments of colonialism (Said 2003), but objectively they also spread modern scientific and technological knowledge and promoted the development of modern cultural education, medical treatment and sports (Coomans 2018; Wu 2015). Over the past 40 years, relevant studies have focused mostly on basic analysis of historical facts (Chen 2007; Dong 201), architectural style "adaptation" (Cody 2003), and economic rationality (Li 2004), thus laying a research foundation to some extent.

However, unlike easel painting which is highly influenced by personal characteristics and artistic attributes, architectural creation and implementation is a process of technical research, development and application in the context of social production; it is restricted by objective environmental factors such as terrain, climate, resource, transportation, economy and even craftsmanship. Architectural design is the observation, analysis, evaluation and comprehensive response to the above factors and their constraints or influences. Inevitably, there will be misunderstandings and confusion if no concrete analysis is performed of technical measures in architectural design that follow practical logic, especially the in-depth consideration of adaptive design thinking of architectural ontology. For example, the architecture of West China Union University (WCUU) is considered "the Chinese roof fastened directly to the top of the British masonry structure" (Cody 2003), and Christian universities express some contempt that the "Sinicization" of their architecture is typically grafting "Chinese roofs" onto Western stacks (Tung 1946): while this kind of roof may seem to have adopted the traditional Chinese timber structure, in fact it is so in appearance only, and the roof is supported by Western timber structure inside. So why not just use Chinese timber structure entirely? And how could this be designed and constructed?

Given the above questions, as a legacy that persists, architectural technology initiatives and adaptive design thinking in architecture for Christian universities also still in use are instructive and useful in the context of global flow today. This paper focuses on the architectural activities of Christian universities in China in the early 20th century, and especially the material selection, structure, construction, decoration and craftsmanship of the "Chinese roof" as implemented at WCUU (Figure 1). The paper aims to prove from an engineering perspective that it is possible to translate the "Chinese roof" based on the main technical carrier of Western masonry structure despite many challenges.

WCUU was chosen for this study mainly because it was the first project to actively integrate Chinese and

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Figure 1. Van Dernan Hall in WCUU ca. 1920. Source: //library.vicu.utoronto.ca/exhibitions/vic_in_china

Western cultures in campus planning and the architectural design of Christian universities (Cody 2003). If we use "the Chinese roof fastened directly to Western walls" as the only dating criteria, Schereschewsky Hall in Shanghai St. John's University and Martin Hall in Lingnan University were constructed earlier. But if we take campus planning and architectural design into consideration, WCUU was constructed the earliest of all (Dong 2006). It is already known that from the beginning of the WCUU campus planning and design in 1912 to completion of its main buildings in 1928 (Dong 2010), Chinese scholars had not yet made any truly valuable academic study of the history of Chinese architecture, and the German architect Boerschmann was the only one that had a professional knowledge of architecture and the newly published results of fieldwork (Lai 2011): that was the professional knowledge base the project architects had at that time. Thus, the campus planning and architectural design of WCUU was indeed the pioneer since it not only lacked precedents for reference but also research materials on Chinese architecture based on the academic system of modern architecture.

So, what methods did the designers adopt to adjust the relationship between Western architectural techniques and the "Chinese roof" without precedents and references? What was the result? And what is the significance and value of the design today? These questions will be addressed with case analysis based on literature, archives and fieldwork below.

2 FRED ROWNTREE AND THE ARCHITECTURAL DESIGN OF WEST CHINA UNION UNIVERSITY

Although WCUU has a large campus and required a long construction cycle involving many professionals in architectural activities, undoubtedly the most important initiator was Fred Rowntree (Figure 2), the British architect responsible for the original version of the campus planning and architectural design. Rowntree was born into a wealthy merchant family in England in 1860. He received his primary education in York, was apprenticed in an architect's firm, and then moved his office to London in 1890. Fred and his two sons co-founded the Fred Rowntree & Sons architects in 1912, and they won the campus planning and design competition for WCUU in Chengdu, Sichuan, China. Four architecture firms from the UK, the USA and Canada participated in the competition: the London firm Fred Rowntree & Sons; a Bath firm Silcock & Reay; a New York firm Stoughton & Stoughton; and a Toronto firm Gordon & Helliwell (Anon 1913). The commission unanimously selected the scheme of Fred Rowntree & Sons architects (Anon 1913), and invited the architects to China for a field survey (Anon 192,Anon 1924). Rowntree did a lot of work after his long journey to Chengdu:

Figure 2. Image of Fred Rowntree (1860–1927). Source: //www.guise.me.uk/rowntree/fred/index.html

> *"Before commencing building operations, the senior partners visited the site and discussed various problems, not only with the members of the Senate, but also with the three leading Chinese statesmen of the Province, who welcomed the suggestion that the design of buildings should be Chinese in character, politely adding that if they were carried out in that spirit, they could copy them! An endeavor has been made to maintain the forms, texture and coloring handed down from past history, and to adapt these to modern requirements, with judicious and harmonious use of such materials and forms of construction as the country can best supply" (Anon 1924).*

Rowntree not only conducted the on-site survey and customer communication but also inspected the palace of the Qing Dynasty in Beijing and began designing back in England. He never returned to China after that first and only visit. So, his remote design work inevitably relied on the project leader to improvise and adjust as required on site. Raymond C. Ricker, an American missionary architect, along with Walter Small and E. L. Abrey, two Canadian missionary architects played an important role. This paper only covers the former due to its limited length.

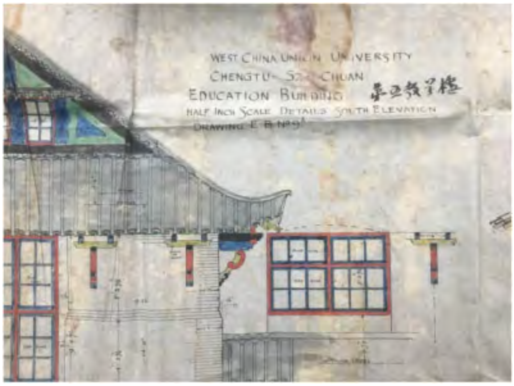

Figure 3. Painted scheme drawing of West China Union University completed by Fred Rowntree & Sons Architects Source: Archives of Sichuan University, China.

There are three kinds of historical materials related to this research: the original design drawing in Archives of Sichuan University, Chengdu, China (Figure 3); archives related to United Board for Christian Higher Education in Asia kept at Yale University, the USA; and early reports in British and American professional journals, such as *The Builder*, *The Building News* and *The Architects*.

3 TRANSLATION: WESTERN ARCHITECTURAL TECHNOLOGY VS. THE "CHINESE ROOF"

Following the opening of global routes at the beginning of the 16th century, one of the biggest challenges the colonists faced was how to adapt construction activities to a specific environment. They gradually developed design and construction suitable for tropical and subtropical regions such as the "veranda style" (Fujimori 1993). In Chengdu, a city in the southwestern corner and deep in the interior of China, British architects inevitably had to think about such matters:

> *"The Medical college and Normal college are to be built in accordance with the most approved Western methods of planning whilst the main idea of design has been to adapt to the best National characteristics to modern needs by the judicious and harmonious use of such materials and forms of construction as the country can best supply. It is intended to use a local gray thin brick for the general buildings, and to cover the roofs with local tiles" (Anon 1913).*

Rowntree was evidently aware of the importance of environmental adaptability from the very beginning, taking appropriate measures in material selection and construction. He specifically required the use of local tiles for his "Chinese roof", which can be recognized as a sensible choice – at least in economic terms. However, architecture is a kind of complex material production activity across disciplines, and "representation" is not that easy. The following analysis in this case is based on original design drawings, fieldwork and related literature.

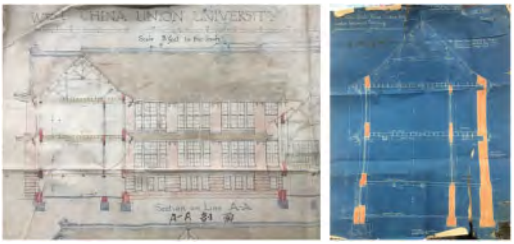

Figure 4. Drawing of School of Medicine and Dentistry. The design of roof has not been deepened from scheme (left) to construction drawing (right) Source: Archives of Sichuan University, China.

3.1 *The "Chinese roof": What if the load is too large due to the tiles or craftsmanship?*

While it might be sensible to use the local building materials in general, they might not suitable in all cases. This is one of the difficult aspects of constructing the "Chinese roof":

> *"I have learned from experience in these buildings that I should not attempt to follow as closely as a builder in America is supposed to follow the Architects plans. There have been very grave difficulties in the construction of the roof of the Administration building, owning to the trusses being in no case real trusses, i.e. structures stable in themselves, without the aid of supporting walls or buttresses to take up the thrust. These have not held up under the great weight of Chinese tiles, and have caused spreading, where as a stable truss would have given no trouble, and save us time and expense. I feel that the design of buildings should be made such that the roof truss can be built to take their own thrust, and that these trusses should be so designed by the architect" (Ricker 1920).*

Thus, it was not necessarily possible to simply graft Chinese tiles onto Western trusses: the principal architect in London was not familiar with Chinese materials, construction and craftsmanship, as can be seen from the sectional view of School of Medicine and Dentistry, which did not explain the roof structure or how the tiles would overlap. Doors and windows, decoration and ceiling were all well designed from scheme drawing to construction drawing (from whiteprint to blueprint), but there was no further detailed design for the roof construction (Figure 4) – it was constructed based on the drawing and design of the client architect on site (Ricker 1920).

There were doubts as to whether Chinese tiles were really so much heavier than Western tiles. The answer is that they were not. As sintered clay products, the thickness of Western tile was similar as that of Chinese tile. The Western tile was even a bit thicker and,

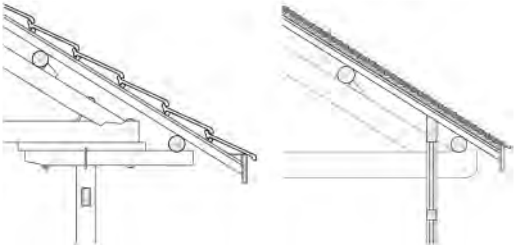

Figure 5. Comparison of the craftsmanship in a Chinese tile roof (right) and Western tile roof (left), with which the No. 1 Granary was built in Enshi in 1951 Source: drawing by the author.

Figure 6. Small tiles being laid for the “Chinese roof” project at West China Union University Source: Archives of the United Board for Christian Higher Education in Asia, ubc416-5203. Credit: Digital Collection: Divinity Library Photographs, Yale Divinity Library.

therefore, heavier. But because the Western tile itself was generally equipped with hooked “back claw” and downward “front claw”, lapping length of tiles was very limited when laying with wooden tile batten; tiles could be fixed without lime plaster (mortar) and expel water. While there was no “claw” on Chinese tile, greater lapping lengths had to be set aside between tiles: seven tenths or six tenths (Li 2011; Liang 1981). Roof boarding and sheathing tiles have to be sintered for more sophisticated architecture.

Therefore, the “Chinese roof” above the rafters is very heavy (Chen 2019) – much heavier than the Western roof even, by about 150 kg per square meter according to rough calculations. The actual thickness of tile laying is 2～3 layers with lime plaster, so the tile itself is not heavy (Figure 5). These are obviously the technological features of the Chinese tile roof’s material and its construction craftsmanship. If a Western roof truss is used underneath a “Chinese roof”, it is vital to use a temporary support during construction to avoid collapse. It just proves that it is not appropriate to consider the “Chinese roof” as fastened “directly to the top of the British masonry structure”: it is not easy to lay tiles on roof trusses, which is the most challenging part of the project to represent the “Chinese roof” (Figure 6).

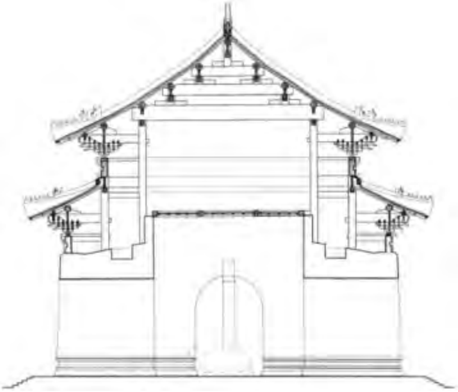

Figure 7. Construction principle of raising and depression of the “Chinese roof” of the Official Building in Northern China Source: drawing by the author.

3.2 *The “Chinese roof”: What if the raising and depression of the roof and Western truss do not match?*

Even more difficult than dealing with the overloading of the roof is combining the appearance of the “Chinese roof” with the Western roof truss. For imperial buildings in ancient China (especially in northern China), the upper part of the column head is basically a cascading structure; namely the post-and-lintel construction (抬梁). The “Chinese roof” is made by raising the horizontal spacing between purlins, and different slopes of the rafters above the horizontal spacing between purlins are formed due to the intended difference of “raising” range (Figure 7) –“raising and depression” (举折 also called 提栈 in southern China) (Yao & Zhang 1986) – while there is also raising and depression for column and tie construction (穿斗, Liu 1987). Thus, there is an unbridgeable gap between the vertical upper chord of the Western sloping roof truss and the appearance of raising and depression in the “Chinese roof”.

So, the design difficulty in the architecture of Christian universities lies in how to use the upper chord to make raising and depression for the continuous straight Western roof truss in order to imitate the roof curve of the Chinese timber structure. The architecture at WCUU and the main building of Jinling College built in 1923 both adopted rough solutions such as directly placing the Western roof truss without any treatment on the front and rear exterior walls, with merely one fold created with a flying rafter (飞椽) at the eaves (Figure 4 right). Except for the eaves, it can in a sense be regarded as having no raising and depression construction. The roof looks acceptable from a distance, but close up the upper roof can be seen to be too high and flat, which makes it heavy and unwieldy. It lacks the lightness and vividness of the prototype of the “Chinese roof” (Figure 8).

After the 1920s, architects studying in Europe, America, and Japan came back to China and made

Figure 8. In the architecture of WCUU, there was no raising and depression in the roof truss (left), making it heavy and unwieldy (right). Source: photo by the author.

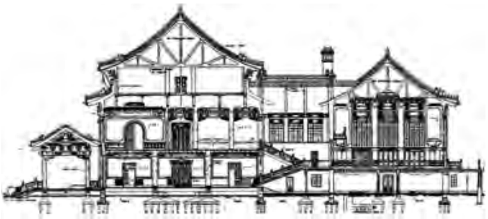

Figure 9. Ministry of Foreign Affairs in Nanjing in the 1930s, designed by Tingpao Yang, with curved upper chord of the reinforced concrete truss Source: *Chinese Architecture*, vol. 2.1934 (11+12).

a contribution to Chinese architecture. Their specific practices in similar design projects improved. For example, they used short supports to adjust the variation in height for the purlin or designed the chord of the upper truss as an arc directly (Figure 9). Even the famous architect Hua Nangui specifically studied how to make a raising and depression construction with the Western truss (Hua 1928). These can be closely related to the intuitive lessons and experience offered by the incomplete approaches of the Western architects above.

3.3 *The “Chinese roof”: What if decoration materials and craftsmanship have special requirements from regional products?*

Besides the lightness and vividness of the roof, the prototype of the “Chinese roof” – that is, the roof of the official building in northern China – also features colorful decorative elements such as immortal animals and Lonewen (龙吻, ornaments on the roof ridge, including early Chiwei 鸱尾, an ornament on the roof ridge in the shape of an owl’s tail), most of which are luxury glazed products, so as to underscore power and dignity. That is why glazed building materials in ancient China were mostly produced in the north, concentrated around the capital, especially in Shanxi. Although production extended to the south in later times, it was mainly concentrated in the South Yangtze River regions (Fan 2011). Obviously, Sichuan, far from the center of imperial power, is not an area of developed glazed technology. This can be indirectly confirmed by resistance among local officials in Sichuan province when the Nationalist government tried to promote the “National Standard Patterns of Public and Private Buildings” (全国公私建筑制式图案) in the 1940s (Li 2004), because it was difficult to buy roll roofing tiles locally, not to mention glazed tiles.

Figure 10. Exterior of detailed decoration of clay plastering on the “Chinese roof” of West China Union University Library Source: photo by the author.

Therefore, in the case of the many “Chinese roofs” of WCUU, Rowntree was not familiar with the decorative subject of the various details featured on Chinese official buildings and invented all sorts of strange-looking animals. Nevertheless, it was wise of him in terms of material selection and craftsmanship to make use of the local clay plastering process, namely “water making” (水作, Figure 10), instead of sticking to the rules of official buildings, a detail confirmed by the engineers responsible for the maintenance after the earthquake in Wenchuan in 2008.

Since the original design drawings lacked an in-depth consideration of the detailed decoration, and the fact that original design drawings could not be used properly and had to be redrawn, as reported by Raymond C.

Ricker, the author can reasonably deduce that the decision to adopt local building process for the decoration of the “Chinese roof” in this project was made by Raymond C. Ricker and other architects on the site following careful consideration.

> *“Other drawings that are provided by the architect frequently have to be entirely redrawn, as the architect, being unfamiliar with the construction of Chinese roofs, can give only a general idea of what he has in mind, and we approach as nearly to that as it is possible to do; but it has been necessary for me to entirely redraw every roof drawing that has been sent. This takes no small amount of time and necessarily involved considerable change in some places, to make construction possible” (Ricker 1920).*

Indeed, what is more important to architecture and the architect than the completion of the construction? If the building cannot be built, nothing is possible.

4 CONCLUSION

The construction process of the architecture of WCUU has been clarified in this paper through a brief review of the design competition, site visits and design process, based on the technical literature, historical archives review and fieldwork, with the following conclusions:

First of all, Fred Rowntree, the principal architect, was a practitioner of independent mind whose intentions were exploration. He not only contributed to the hybridization of campus planning and appearance of the buildings to integrate Chinese culture and Western culture, but also consciously paid attention to the physical environment, applied local materials and craftsmanship, and roughly reproduced the Chinese architectural style in technical details. Raymond C. Ricker, the American architect appointed by the client as “the Superintendent of Construction”, played an extremely important role in the building site in China

Nevertheless, due to a lack of experience of the environmental complexity of Chinese architecture and limited basic knowledge about the study of Chinese architectural history in the early 20th century, the specific design measures employed for the project were still unsatisfactory. This does not affect the pioneering significance and status of the attempted design.

Secondly, as a design intention, environmental adaptability gave rise to a hybrid strategy of technical design and selection. The architectural design of WCUU clearly aimed to engage in cross-cultural communication and achieved some initial success. It demonstrated the power of practical logic from a building engineering perspective: it is possible to translate the “Chinese roof” using the main technical carrier of Western masonry structure in engineering, but it also involves many challenges – the thinking and experiments of Western architects in working to solve such challenges may have contributed to an interesting change of construction cultures from hybridization to integration.

Moreover, the adaptive decisions and measures taken by the principal architect Fred Rowntree and architect in charge on site Raymond C. Ricker were, in fact, quite sensible. A realistic attitude also verified hybridization as a means of creative improvement and technical selection of Chinese architects in different later periods. It even inadvertently became the very beginning of Chinese regionalism; critically, not as a strategy of resistance to modernism in architecture but rather as a simple consideration of feasibility in construction. Such projects can serve as a meaningful reminder of the romantic nature of the regionalism of architecture.

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History of Construction Cultures – Mascarenhas-Mateus & Paula Pires (eds)

Creating an American Methodist college in China: A building history of Soochow University, 1900–1937

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ABSTRACT: The paper examines the American influence and the "new" local tradition in the development of the old campus of Soochow University (Suzhou) in 1900–1937. It traces how the campus and the earliest buildings of Soochow University were built and evolved, going from the early golden era (1900–1927) to the Nationalistic period (1927–1937). The paper examines the various factors in play and their impact on the design and construction process: the physical environment of the site; the involvement of Western and Chinese architects as well as local builders; the sources of building materials and construction funds; and the contemporary building construction manuals. This analysis reveals that the story of Soochow University offers a vivid illustration of the major challenges faced in building Sino-Western university campuses in early 20th-century China.

1 INTRODUCTION

In the late 19th century and early 20th century, Christian missions played a critical role in bringing in Western construction cultures while driving changes in the urban landscape in both coastal and inland China with the building of churches, the foundation of Christian schools and the promotion of Western learning. At the turn of the 20th century, following China's defeat in the first Sino-Japanese War, the Imperial Civil Service Examinations were abolished. This gave rise to a rare occasion where the interests of Christian missions and those of the Qing Court were in tune concerning the need to modernize educational institutions (Xu 1993). This enabled a golden era for the creation and development of Christian-led schools and universities all over China, among them Soochow University, which is, in fact, one of the earliest Christian colleges in the country.

The main sources of this study are: 1) Archives of the United Board for Christian Higher Education in Asia linked to Soochow University held at the Yale Divinity School Library; 2) archives concerning building, surveys and repairs preserved by Soochow University Archives and Suzhou Municipal Archives; 3) contemporary Chinese and English building construction manuals and textbooks; 4) a comprehensive on-site survey and building documentation of Soochow University carried out in 2019.

2 AMERICAN INFLUENCE

2.1 *The university campus as pedagogy*

"Pedagogy" refers to the philosophy of education and resulting teaching methods. In traditional Chinese society, the appreciation of Confucian values and the adherence to related ethical codes was illuminated by the educational institutions represented by the "*Shuyuan*" (or the Academy), and its spatial relationship of the memorial temple, the library and the lecture hall. By contrast, although the early Christian universities in China were founded due to diverse historical reasons and in different social environments, they all tried to implement their educational philosophies in the process of building their campuses as a way of promoting Christianization. From the perspective of the missionaries of the Methodist Episcopal Church, South (MECS), who founded Soochow University in 1900, the university campus as pedagogy served a twofold purpose: first and foremost, to provide Chinese students with a Christian learning experience, but also to provide the Chinese Government and its new Government Schools with an inspiring model to follow in the early stages of Chinese educational modernization.

Western educational thinkers did not have a consensus view of the material form – i.e. the design of campuses and their buildings – of Chinese modern higher education. The mainstream approach was to follow the traditional Chinese style, while a "Western style", as found in Soochow University, also emerged in a minority of cases. In today's architectural research, the Soochow campus is often referred to in studies dealing with Chinese Christian universities as a whole. However, such research to date has primarily focused on the mainstream Chinese style. Consequently, the Soochow campus as an example of the Western style has not been looked at in detail and is thus worthy of further investigation.

The MECS envisioned the creation of a university in China as an American-inspired institution that could provide a model for Chinese higher education. The founder Rev. Y. J. Allen had high hopes for Soochow

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University's identity as a new paradigm of Chinese universities: "We hope to have a model, an example of schools, (…). That is a model of its kind, and I believe is to be the progenitor of schools as well as the mother of pupils." (General MECS 1901: 366).

MECS Bishop A. W. Wilson remarked on the plan of the first building they proposed to erect in Soochow University: "We want to get the Chinese impressed and make them understand that we are going to do just as well for them as we would do for our young men at home." (General MECS 1901: 393).

Unlike most Christian universities founded subsequently, the Soochow campus was planned at a critical time when the Qing government incubated the Renyin Educational System (1902) and the Guimao Educational System (1904) was in the offing. Although these new national policies were intended for government schools, MECS missionaries such as Rev. Allen and Rev. Dr D. L. Anderson had been paying close attention to the relationship between the Christian schools in China and the trend of Chinese education reform at that time, with a view to achieving dialogue and influence. In brief, the guiding spirit that Chinese authorities expressed in the Guimao educational system on the construction of government schools was to imitate "foreign patterns": "(…) It is urgent to find another high and dry land with ample space, refer to the regulations of university campuses in foreign countries, and construct buildings in succession, following the school institution (…) If you check the school campuses in other foreign countries, you find out that (…)" – Presented School Regulation: "Outline of Academic Affairs", 1904.

This prevailing atmosphere of "learning from the outside world" during this critical period may have provided the early MECS founders of Soochow University with inspiration and encouragement when they were choosing the form of the campus, even though the Regulation specifically mentioned Japanese ones as a nearby example of foreign schools and allowed the flexibility to "modify according to the circumstances". The writing of the *Guimao Educational Systems* was based on the Japanese experience, while the construction practice of the Soochow campus derived from the American experience: to some extent, both of them in their own ways drew from foreign models to fill the gaps and construct modern institutions in China.

2.2 *Site selection*

In order to realize the MECS vision of a typical American university campus in China, as Wang (2006) noted, "social tolerance" from the locals may have been necessary. However, Suzhou's acceptance should not be taken for granted. Although only 80 km away from Shanghai, this city had a more conservative social attitude to Christianity. For example, the Yangjiaqiao Catholic Church, built around the same period as Soochow University in 1893, was "squeezed out" in the outer suburbs of Suzhou, 3 km west of the ancient walled city, relying on the funds raised from converted fishermen, and depending on the craftsmanship of local Xiangshan Gang artisans for expedient construction.

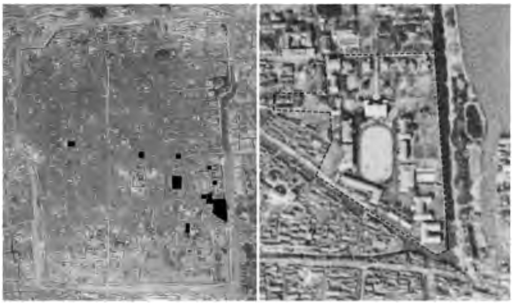


Figure 1. Aerial view of Suzhou old city from the 1960s, with the locations marked in black denoting the MECS sites of activity in the early 20th century (left); magnified view of the location of Soochow old campus in the 1960s (perimeter denoted with a dashed line) (right) (source: US Geological Survey, DS1106-2086DA072_b.).

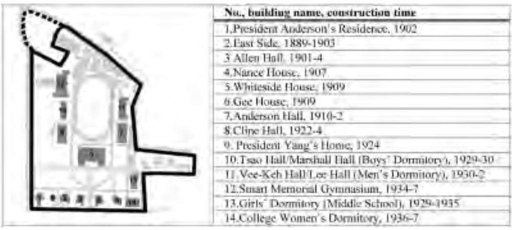
MECS had been operating in Suzhou since 1870, and a Christian community comprising churches, hospitals and schools of various kinds had developed by 1900 (Figure 1). The MECS missionaries viewed the strong tradition and quietness of Suzhou as a virtue. For instance, at the New Orleans Missionary Conference in 1901 the MECS missionary Rev. A. P. Parker expressed awareness that Suzhou had always been an education center of China with a profound tradition. Based on his understanding that literati were the privileged class in the city, he reasoned that operating a university in Suzhou could lead to a wider influence over the entire Chinese empire. Additionally, he noted that, compared to the bustling Shanghai, Suzhou provided less temptations for young students, allowing them to concentrate on studying (General MECS 1901: 173).

To make an impact in such a conservative city, MECS missionaries chose a "top-down elite route". In the USA, they promoted the Soochow University project to Bishop Wilson and Bishop Galloway, thereby securing adequate construction funds through the General Missionary Conference. In Suzhou, they sought support from the American Consul-General John Goodnow to negotiate the purchase of the plot for the University campus with Chuanlin Lu (鹿传霖), Viceroy of Liangjiang.

Interestingly, while the MECS accounts describe the Soochow University project as "heartily welcomed" by the local gentry, many native Chinese accounts describe it in negative terms. Therefore, attitudes may have actually been divided in the society. The contest and compromise of different interest parties eventually led to the selection as the site of Soochow campus of the Tiancizhuang (or "Heaven Gift Market") lot located in the southeast edge inside the walled city, originally an "unfavored" land where the victims of the Taiping War were buried. It is the marginalized urban area – so reminiscent of the process that led to the site selection for the British

Figure 2. Water Tower of Soochow University built in 1907 (left); Methodist Mission Landing built in 1911 (Soochow campus to the left) (right) (source: Soochow Hospital Extras 1917: 43, 55).

Table 1. Earliest buildings of Soochow University.



No., building name, construction time
1.President Anderson's Residence, 1902
2.East Side, 1889-1903
3.Allen Hall, 1901-4
4.Nance House, 1907
5.Whiteside House, 1909
6.Gee House, 1909
7.Anderson Hall, 1910-2
8.Cline Hall, 1922-4
9. President Yang's Home, 1924
10.Tsao Hall/Marshall Hall (Boys' Dormitory), 1929-30
11.Vee-Keh Hall/Lee Hall (Men's Dormitory), 1930-2
12.Smart Memorial Gymnasium, 1934-7
13.Girls' Dormitory (Middle School), 1929-1935
14.College Women's Dormitory, 1936-7

Figure 3. Growth of the campus between 1900 and 1937 (drawings by Yiting Pan).

Settlement in Shanghai – that gave more freedom in the planning and designing of the Soochow campus. The corresponding price paid for maintaining this relative autonomy is that all fundamental infrastructure, including power and water supplies, needed to be created from the ground up (Figure 2). This process was highlighted by the digging of a well for drinking water as deep as 333 feet (ca.100 m) in 1906 and the building of the University's own power plant in 1921.

Figure 4. Second phase of the campus (source: vintage post card of Soochow University ca.1919).

Figure 5. Fourth phase of the campus (source: Special Collections, Divinity Library, Yale University, United Board for Christian Higher Education in Asia, RG011-415-5874-5015).

2.3 *Campus planning*

The development of the Soochow campus can be divided into four phases (Table 1, Figure 3). The contract of the first building was signed on 12 December 1901 and the project started two weeks later. It can be seen that the construction of Allen Hall and the President Anderson's House had taken into account the general layout of the first phase of the "main building – teachers' community" system of the campus (1900–1909). This progressive campus development by phases probably directly drew from American universities such as Vanderbilt University which also started from the main building and the faculty residences. This private university founded by the MECS Bishop McTyeire in 1873 in Nashville, Tennessee (USA), where the MECS was headquartered, had trained and dispatched a large number of missionaries to China. Founders of Soochow University such as Rev. Allen, Rev. Dr J. W. Cline, Rev. Dr W. B. Nance, and many pioneering teachers such as N. G. Gee, R. D. Smart, E. V. Jones, J. Whiteside are all graduates of Vanderbilt University. Given this academic lineage, after taking charge of Soochow University, they may have been naturally inspired by their alma mater, from teaching philosophy to campus setup.

The second to fourth phases focused on the quadrangle (Figures 4–5). Although the campus's irregular boundary – with surrounding picturesque water-town scenery – meant that its site conditions may have been suitable for a "organic" plan like that of the early Vanderbilt campus, the core area of?? the Soochow campus consistently evolved toward a typical American "Mall" model focusing on axis, symmetry and monumentality (Figure 6). This is likely because the MECS sponsors viewed the Western model as an "environmental education" to bring to Chinese students the teaching of Western order and rational thinking.

The mixed functional configuration could also be regarded as another pedagogical strategy of the Soochow campus. The quadrangle – surrounded by the teaching buildings, the science hall, the gymnasium and the student dormitories – created a mixed campus community where learning and living were closely

Figure 6. Buildings of the quadrangle, Soochow campus (source: Special Collections, Divinity Library, Yale University, United Board for Christian Higher Education in Asia, RG011-415-5874-5014; 5002; 5003; 4999; 4998; 5001).

integrated. In contrast to the typical American university where sports fields were often set aside in a corner of the campus, the sports court of the Soochow campus was placed in the central "Mall" contoured by a curved standard track, making the surrounding buildings with verandahs and windows a platform for watching sports activities.

3 "NEW" LOCAL TRADITION

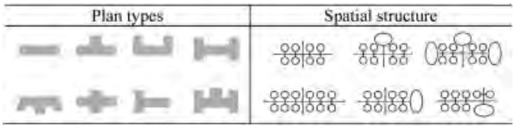
3.1 *New trade in foreign-style architecture*

The successful completion of the Soochow campus with such distinctive Western characteristics was undeniably due to the rapid development of the new trade in foreign-style architecture in Chinese treaty ports (e.g. Shanghai) since the mid-19th century and especially in the boom years 1900–1930. It was a new industry characterized by ever-growing transnational construction activities capable of garnering domestic and international funds, calling on teams of Western and Chinese practitioners, mobilizing native and foreign material supplies, developing new building types based on Western prototypes and local needs, and integrating Western scientific knowledge and local expedient innovations.

The importance of the Soochow campus lies not in the achievement of one single Western-style building (in this respect, it has little to claim), but of the collection of buildings that were developed over a period of almost four decades, representing different solutions and figuratively serving as a vibrometer that recorded the turbulence of political, social and technological transitions.

During the two decades that followed the foundation of the Soochow campus in 1900, Christian schools run by foreigners were outside the control of the Chinese governments. In 1906, the Education Ministry of the Qing Dynasty promulgated the edict on "Foreign Universities to be Exempt from Filing a Case by Provincial Governors", which allowed Christian universities not to comply with any guidelines for facility construction of government universities in the Presented School Regulation (1904), and freely choose their construction standards. This led to Soochow University's experiment with educational buildings that had a strong religious inspiration and Western flavor (Figure 6).

Table 2. Plan schemes of Soochow university buildings. (Drawings by Xingxing Wu and Yiting Pan).



The first building of the Soochow campus, Allen Hall (built in 1901–4), which is today regarded as the work of the Shanghai-based British architectural firm Atkinson & Dallas (Wright 1908), demonstrated strong appreciation of the colonial style, with colonial verandahs and Queen Anne features popular in the 19th century and until the early 1900s in Chinese treaty ports. Although the contemporary book *Chinese Education Directory* (Gee 1905) described Allen Hall as "built in the best style", this trend was terminated soon, as W.B. Nance recalled that "Americans had begun to react against the high ceilings of Anglo-Indian tradition" and buildings were no longer built with verandahs. However, the religious characteristics remained in educational buildings of Soochow campus built over the 1910–20s, as illustrated by the choice of the Collegiate Gothic Revival style in Anderson Hall (built in 1910–2) and the simplified Gothic style with Art Deco elements in Cline Hall (built in 1922–4). J. W. Cody's book *Building in China* (2004) revealed that the American architect Henry Murphy met the president of Soochow University and probably became involved in the design of the Soochow campus in the early 1920s.

Regardless of the architectural styles chosen in the different phases of its construction, it is notable that Soochow University was one of the earliest to use and develop the I-shape prototype of educational buildings in China. Indeed, the outlines of seven of its buildings were essentially the addition and subtraction of a simple I-shape scheme (Table 2). According to this design rationale, a variety of specific architectural plans with a certain degree of complexity were designed for both teaching and dormitory buildings. The main entrance was located in the center of the long façade, while the floor plan was divided by cross-intersecting corridors, which occupied 20–30% of the total area of each floor. These corridors connected all the rooms of the same level, maximized the functional area of the building, improved the efficiency of space use, and allowed good natural lighting and ventilation. Additionally, particular functional needs in the homogeneous space – e.g. the bell tower, the auditorium, the library, and the lecture hall – created a unique spatial form both internally and externally. It is notable that many Christian university campuses built after the Soochow campus, such as Ginling College for women and Hangchow University,

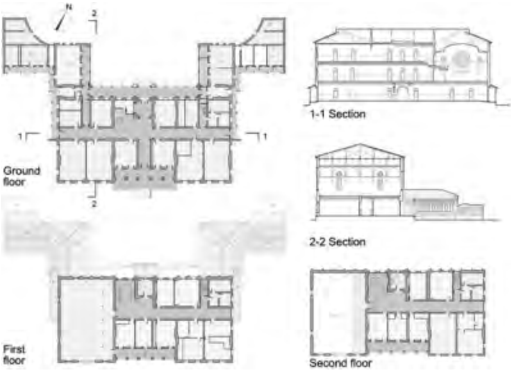


Figure 7. Plans and sections of Allen Hall (built in 1901–4) (drawings by Suzhou Jicheng Conservation Co. and Soochow University students 2019).

Figure 8. Allen Hall: chapel (left) and northern verandah (right), ca.1918 (source: GCAH Archive: Mission Photograph Album – China #13 page 0089, 86447; page 0092, 86454).

applied and further popularized the I-shape model in educational buildings (Figures 7–8).

The loose atmosphere dramatically changed in the 1920s, when a series of policies for "Private Institutions" by the subsequent Republican government progressively strengthened the supervision of Christian universities, including the replacement of foreign university presidents with Chinese ones. Specifically, during the Nationalistic period (1927–1937), the fourth construction phase of the Soochow campus drifted toward dereligionization and a certain degree of sinicization in architectural features. All the buildings built during that period – after the first Chinese President Y. Yang (杨永清) took over in 1927 – including Tzao Hall, Vee-keh Hall, Smart Memorial Swimming Pool, Smart Memorial Gymnasium, and the two female student dormitories, were the works of the Shanghai-based Eastern Asia Architects & Engineers Corporation (EAAEC).

Interestingly, the sinicization of the faculty of Soochow University paralleled the sinicization of the EAAEC ownership and staff. The former manager and founder of EAAEC was the Russian architect W. Livin-Goldstaedt. His choice of the name EAAEC for his firm, which features the straightforward "Eastern Asia", reflected his desire to build a team of foreign architects designing for China (East Asia), especially for government departments, and his proud achievements were highlighted by his participation in the 1925 "Chinese-style" Sun Yat-sen's Mausoleum Competition. He submitted three projects and outranked most of his competitors, achieving fifth, sixth, and seventh place nationwide (Courtesy H. Zheng). C. K. Chien (钱昌淦)'s takeover in 1927 opened a new chapter for EAAEC. His Chinese identity combined with his American education experience, parallel in many ways the development of Soochow University. Under the pressure of growing nationalism, President Yang in 1935 still affirmed "the mission and function" of Soochow University "as an educational institution", "as a Christian enterprise", and "both as an expression of international friendship and as an agency for its promotion" (United Board, RG011-270-4308: 5–6). Clearly, EAAEC defended the international character of the Soochow campus in the projects they developed between 1927 and 1937, which used an essentially Western yet more neutral architectural language. (United Board, RG011-270-4309: 541-2) Meanwhile, more obvious Chinese elements, such as rockwork and traditional pavilions, were integrated into the campus landscape, subtly connecting the University with the picturesque Suzhou ambiance beyond the campus wall, thereby appeasing the Nationalists' hostility toward Western influence.

3.2 *New industry of building materials*

While the new trade of foreign-style architecture was most prosperous in big international treaty ports like Shanghai, Suzhou heavily depended on Shanghai as an important trading center for technology transfer and imported materials distribution. Indeed, not only the architectural firms involved in the construction of Soochow University were mostly based in Shanghai, but also many new types of building materials used in Soochow campus appeared to be supplied via or from Shanghai. For instance, after steel windows from abroad began to be introduced in Shanghai around 1920, imported steel sash windows soon appeared in Cline Hall of Soochow University built between 1922–4.

While the Soochow campus was being developed, the 1920s witnessed a trend that involved the transfer of manufacturing technologies from foreign companies to Chinese ones and the rapid development of Chinese production capability in new types of building materials. For instance, the Smart Natatorium in the Soochow campus (built in 1929) used the ceramic mosaic tiles produced by the Chinese National Eng. & Mfg. Co. in Shanghai. In the 1920s–30s, with the rise of the "National Products Movement", advertisements of Chinese building material manufacturers and building contractors – emphasizing their "national" or "Chinese" characteristics – began to appear on the pages of the university magazine *Soochow Annual* (which were previously occupied by "luxury goods" such as gentlemen's suits and watches), including Shanghai Portland Cement Works, Ltd., China Portland Cement

Figure 9. Main communication routes around Suzhou, 1933 (source: modified from *China Industrial Handbooks: Kiangsu* 1933).

Company, Ltd., B.S. Chang & Co. General Contractor, Wuxi Shiye Construction Co., and the Old Zen Tai Chuan Kee Co. (building hardware) – some of which are confirmed suppliers of the Soochow campus projects during the Nationalistic period (United Board, RG011-270-4309).

Despite the increasing mobility of emerging building materials from Shanghai to Suzhou, the means of transporting them remained primitive. Although the British-built Shanghai-Nanking Railway (also connecting Suzhou to Shanghai) was built in 1908, for many subsequent years heavy building materials (e.g. building ceramics and timber) continued to be carried mainly by boat, as only high-end or machinery-related materials (e.g. silk, coal, and ore) could be transported by rail (Anderson 1911) (Figure 9).

Suzhou never developed into an industrial city in the early 20th century and only counted a very limited number of large-scale factories (Minister of Industry 1933). However, this does not imply that Suzhou's materials supply for foreign-style buildings was completely dependent on Shanghai. A notable example relevant to the Soochow campus pertains to the supply of bricks used in its construction in the 1920s and 1930s. Some of these bricks were provided by a brickyard called Soochow Brick & Tile Co. (SBTC), established in 1921 by Dr J. A. Snell, a MECS missionary and also the President of the Soochow Hospital (博习医院) owned by MECS. Several sources indicate that this brickyard was an American brick factory with a strong sense of Christianity (Huang 1995; Nield 2015). A revealing example can be found in a letter that Snell wrote in 1921 as the President of SBTC to the editor of the magazine *Clay-Worker* asking for the recommendation of someone with "a strong Christian character" to "direct the burning of brick and tile with a Hoffman kiln" and "act as general manager" (Snell 1921). Shu & Coomans (2020)'s paper noted that a technician named Émile Henry of Manufacture Céramique de Shanghai moved to SBTC in November 1922. Given the timing and the direct involvement of MECS in the foundation of SBTC, the hollow bricks of Cline Hall (1922–4), the red brick veneers and French-style tiles of Tsao Hall (1929–30) and Vee-Keh Hall (1930–2) would likely be supplied by SBTC. The *Report of Soochow University to the China Conference MECS* (1934) also reveals that $1000-worth of bricks used in the Smart Memorial Gymnasium were a donation by Snell through SBTC when Soochow University experienced severe financial hardship (United Board, RG011-271-4312: 7). This building today has become one of the very rare examples of a building featuring clinker bricks in Modern China (Figure 10).

Figure 10. Clinker bricks produced in the SBTC used in the Smart Memorial Gymnasium built in 1934–7 (photos by Yiting Pan 2018).

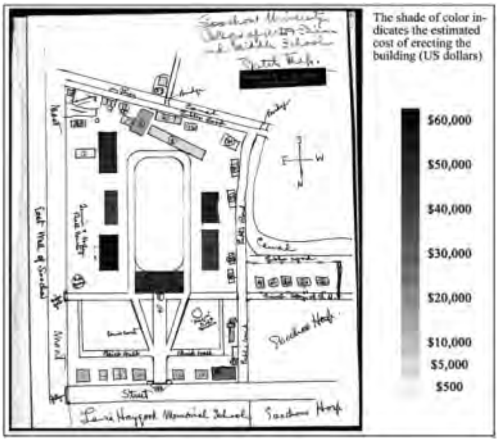


Figure 11. Estimates of the building costs of the Soochow campus modified by Yiting Pan from Rev. W. B. Nance's original sketch map in 1956 (source: Special Collections, Divinity Library, Yale University, United Board for Christian Higher Education in Asia, RG011-269-4285: 6).

The overall technological development taking place at the time did not necessarily lead to the improvement of building quality. On the contrary, the quality of building materials used in the 1930s in the buildings of the Soochow campus was sometimes lower than in the earlier phases. This was determined partly by the wider range of materials that had started to appear in the market, including cheap, lower-quality products. More importantly, however, it resulted from the political turmoil in the 1930s, which led to a tighter budget and more economic construction arrangements. The selection of lower-quality materials was directly reflected by a lower solidity and durability of these structures, as we found in our on-site surveys in 2019. Indeed, we assessed that the more expensive buildings – in accordance with the estimates made by Rev. W. B. Nance in 1956 (United Board, RG011-269-4285: 7–9) – are generally preserved in a better state today (Figure 11).

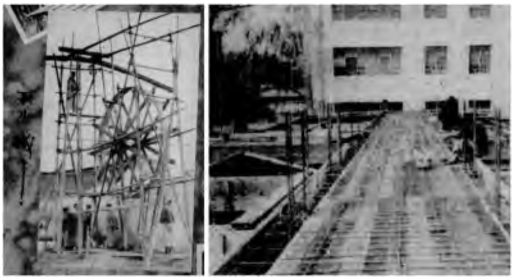


Figure 12. “Water obtaining machine” side by side with the reinforced concrete building site, Soochow campus, 1929–30. (Source: Special Collections, Divinity Library, Yale University, United Board for Christian Higher Education in Asia, RG011-270-4309: 542).

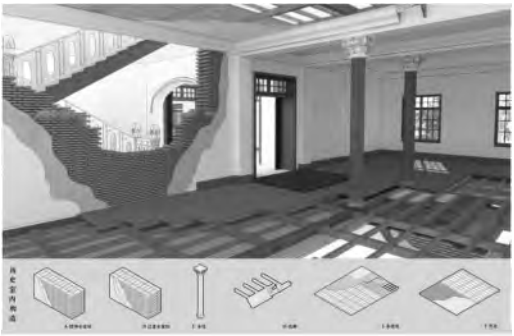


Figure 13. Analysis of the original building construction of Anderson Hall (1910–2) (drawing by Jingwen Zhu, supervised by Yiting Pan 2020).

Figure 14. Insertion of timber columns for strengthening the main timber stairs of Anderson Hall in 1952 (source: Soochow University Archives, JJ152; photos from on-site survey 2019).

3.3 *Mixed building methods*

Historical records reveal that MECS missionaries in Suzhou, such as Rev. C. K. Marshall, Dr J. B. Fearn, Rev. B. D. Lucas or Dr Snell, designed their own residences and some simple buildings of the Soochow Hospital by themselves (*Soochow Hospital Extras*, 1917: 20–6, 40). In fact, MECS missionaries were also involved in directing the construction and repairs of small buildings of the MECS schools (e.g. Anglo-Chinese Methodist College in Shanghai by Parker in 1896) as well as in supervising the design and construction of more complex educational buildings (Wang et al. 2010: 23, 26). For instance, according to Nance’s account, Allen Hall and Anderson Hall were created under the supervision of both the architect and himself (United Board, RG011-269-4285: 3). Dr H. Lu (陆鸿钰) carried out the restoration design and directed repair works of Cline Hall in 1947 (Wang et al. 2010: 306).

The building site of the Soochow campus was not only marked by the scene of MECS missionaries working closely with architectural professionals, but also by an interesting juxtaposition of ancient and modern construction modes. Rare photographs show that when the reinforced concrete structure (a clear element of modernity) of Tsao Hall was erected in 1929–30, native contractors still employed Chinese ancient site solutions for obtaining water to mix with cement for making concrete (Figure 12).

Given that the archives we investigated did not contain any record of the original construction drawings, we sought to gain insight into the building methods adopted in the Soochow campus by carrying out a building survey and comparing our findings against English and Chinese Building Construction textbooks from the early 20th century (Figure 13). We found a general agreement between our on-site observations (e.g. in regard to the flooring, roof trusses, and brickwork) and the construction details presented in these historical construction manuals. This firstly indicates that the building methods used in the Soochow campus were largely inspired by their Anglo-American counterparts. Additionally, this highlights the utility of the contemporary books in understanding and preserving Western-style buildings from the early 1900s in China.

3.4 *Later developments*

After the MECS missionaries left China in 1952 and the Soochow campus was taken over by the Communist government, Western influence seems to have quickly ceased. Follow-up repairs were carried out according to methods that deviated from the original and that at the same time did not entirely follow Chinese tradition (Figure 14). The problem still exists today, and the situation makes these heritage buildings particularly fragile. Shanghai today leads the industry of the conservation of Western-style architecture in China thanks to its more active international presence in this field. The dependence of Suzhou on Shanghai technology in the construction of Western-style buildings 100 years ago seems to repeat itself in their restoration process, lending a hint of déjà vu.

4 CONCLUSIONS

This paper has shown how the Methodist Episcopal Church, South (MECS) implemented their missionary goals and educational concepts in the construction of the material environment of Soochow University. While the role of missionaries in the construction of

Chinese Christian colleges had been largely ignored to date, this paper revealed that the versatile MECS missionaries contributed significantly to the grand educational project that is the construction of Soochow University, including the purchase of lands, the building of infrastructure, the foundation of brick factories, and building supervision, maintenance and repairs.

To gain a more comprehensive understanding, this paper also contextualized the campus development within the political, social and technical transitions in early 20th-century China. It illustrated the extent of the dependence of Western-style projects in Suzhou on the big Treaty Port of Shanghai, revealing a dynamic relationship in building technology transfer from abroad through Shanghai to Suzhou.

Finally, this paper pointed out the importance of taking into account the Western-influenced construction methods in the conservation of the Soochow campus today, raising awareness on the fragility of such building heritage. Technical support – e.g. in the form of conservation products and expertise – from the places that influenced the building of Soochow campus (i.e. Shanghai and abroad) is therefore highly needed to better preserve such heritage today.

ACKNOWLEDGEMENTS

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History of Construction Cultures – Mascarenhas-Mateus & Paula Pires (eds)

“Imposing and provocative”: The design, style, construction and significance of Saint Anthony’s Cathedral, Xinjiang (Shanxi, China), 1936–40

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ABSTRACT: This paper debates the design, style, construction and significance of Saint Anthony’s Cathedral in the county of Xinjiang, Shanxi province, China, which was built by Dutch Franciscan missionaries from 1936 to 1940. The methodology combines archival research in the Netherlands and building archaeological fieldwork in China (June 2019). A rare set of photos of the construction site provides the only information on the building works.

1 INTRODUCTION

From 1870 to 1952, no fewer than 117 Dutch Franciscans were sent to China with the mission of evangelizing South Shanxi. Their central base at Lu’an became the seat of a Catholic apostolic vicariate in 1890. Among other things, the missionaries built churches, residences, schools, orphanages and dispensaries. According to a statistic from 1936, there were three cathedrals, 80 churches and 291 chapels in South Shanxi (Lazaristes 1937: 141–148).

In 1936, the Holy See created the Apostolic Prefecture of Jiangzhou (Kiangchow) in South Shanxi and appointed Father Quintinus Pessers, a Dutch Franciscan, as apostolic prefect. Accordingly, a cathedral was built in 1936–40 on a prominent site within the historical walled city of Xinjiang (Figure 1).

This paper debates the design, style, construction and significance of Xinjiang Cathedral. The methodology combines archival research in the Netherlands and building archaeological fieldwork in China.

Father Constans Kramer, Bishop of Lu’an, wrote that Xinjiang Cathedral was “imposing and provocative” (Kramer 1985: 7). What did he mean exactly? How was this cathedral erected in the context of the Second Sino-Japanese War? Who were the main actors, both Chinese and Western? What construction materials and techniques were used, both Chinese and Western? Finally, to what extent did this cathedral, with its eclectic Western-style façade, express a certain modernity?

2 HISTORICAL CONTEXT: MISSION AND WARS IN SOUTH SHANXI

Xinjiang 新绛县 is a county in the southwest of Shanxi Province, along the Fen River 汾河 about 45 km upstream its confluence with the Yellow River 黄河, in the People’s Republic of China (the county should not be confused with the Xinjiang 新疆 Uyghur Autonomous Region). Until 1912, the name of Xinjiang was Jiangzhou 绛州 (Kiangchow), a name the Church continued to use until 1981 when it changed to Yuncheng Diocese 运城教区. The Cathedral is still standing in Xinjiang, a historical city with rich heritage.


Figure 1. Xinjiang Cathedral from the south-east, after its completion in 1940 (© Het Utrechts Archief, 1224, 291/43).

In 1620, at the end of the Ming Dynasty, Catholic missionaries reached Xinjiang. From there, these Italian Jesuits began to evangelize Shanxi. Father Alfonso Vagnone (*Gao Yizhi* 高一志, 1568–1640), who was a

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famous scholar, died in Xinjiang in 1640. The Jesuits managed to settle in the viceroy's residence at the top of the city and build a church. After their expulsion in 1724, the complex was reassigned to higher education (Dong Yong Academy 东雍书院). A gatehouse with a bell pavilion is the only remaining element from that time (Wang & Feng 2019: 32–34).

Italian Franciscans took over the Jesuit mission in Shanxi. In 1838, the Holy See created the apostolic vicariate of Shanxi, the seat of which was in Taiyuan 太原. In 1890, it was divided into the two apostolic vicariates of North Shanxi ruled by the Italian Franciscans of Taiyuan, while South Shanxi was entrusted to Dutch Franciscans based in Lu'an 潞安 (the current diocese of Changzhi 长治). Because of the growing Catholic population, the apostolic vicariate of Lu'an was reduced twice, with the creation of the apostolic prefectures of Hongdong 洪洞 in 1932 and of Xinjiang on 25 May 1936. The former was entrusted to Chinese clergy; the latter to Dutch Franciscans (Camps & McCloskey 1995: 133–161).

Father Quintinus Pessers (Hong Zhaoming 孔昭明, 1896–1983), a Dutch Franciscan born in Tilburg, was appointed the first apostolic prefect of Jiangzhou (Kiangnan) on 4 December 1936 and immediately began to build a cathedral that expressed the status of the new ecclesiastical territory. Such an undertaking was daring because the circumstances were anything but favorable. Nationalist China was divided and the Communists, after the epic Long March, had settled in October 1935 in the Yan'an 延安 region, ca. 200 km north-east from Xinjiang. Moreover, in July 1937, Japan invaded China and conquered Beijing 北京, Shanghai 上海, Nanjing 南京 and North Shanxi by December 1937. Refugees flocked to Xinjiang, which fell in the spring of 1938. The situation of Dutch missionaries worsened in 1942 after Japan declared war on the USA and occupied the Dutch East Indies (Indonesia). The missionaries were first interned in a camp in Shandong 山东省 and then placed under house arrest in the Beijing Franciscan house in 1943. After the Japanese surrender, several Dutch missionaries returned to Xinjiang in December 1945. The Chinese Civil War between Nationalists and Communists soon turned to the advantage of the latter, who controlled Shanxi from 1947. In 1954, Father Pessers was the last missionary to be expelled from Shanxi, and Chinese priests took over the diocese (Kramer 1985; De Kok 2007: 398–403).

Building a cathedral in such circumstances was very challenging. Work started in 1936, was interrupted at the end of 1937, and resumed and was completed in 1940, including the interior decoration. As of 1952, the cathedral was used as a granary and the other buildings of the Catholic mission became a school. The cathedral was defaced during the Cultural Revolution by taking down the two spires. Eventually, in the 1980s, the buildings were returned to the Diocese, the cathedral was restored and the spires re-established. In 2020, Bishop Wu Junwei 武俊维 and the community celebrated the 400th anniversary of Catholic presence in Yuncheng Diocese in the cathedral, which is its main monument and symbol.

3 SOURCES AND METHODOLOGY

The study of churches and other buildings erected by missionaries in China from the 1840s to the 1940s confronts the researcher with particular methodological issues. On the one hand, difficulties accessing archival sources in China make it almost impossible to find original plans, contracts, specifications, accounts, etc. and to identify architects, contractors, craftsmen, the origin of materials, and so on. With the exception of major cities like Shanghai, Beijing and Tianjin, most archives related to construction appear to have been lost or destroyed. On the other hand, the private archives of missionary institutes in Europe and North America conserve photos of buildings, among which those of construction sites are rather rare. In the case of big projects, photos of plans were sent to Europe and used for fundraising. Missionary archives usually keep a lot of correspondence which sometimes contains allusions to building activity. As for missionary journals, they often mention the newly built churches but carefully avoid boring readers with technical details and do not identify the brother carpenters and builders. A unique manual for church construction in China, published by the Jesuits of Xianxian 献县 in 1926, has been found and studied in detail (Coomans 2014; Coomans & Xu 2016).

The churches themselves, which have passed through the throes of time and history, are researchers' main source. Many, however, have been demolished or transformed; all have lost their original furniture and interior decoration. Building archaeological analysis therefore provides the most accurate information on construction techniques, materials, masonry and roof structures, making it possible to identify the process of reciprocal influences between Chinese and Western projects, techniques and styles, as well as the infinite creativity resulting from these hybridizations on the path to modernity (Coomans 2018; Coomans & Xu 2015). Finally, oral sources are of crucial importance in China. Interviewing elderly persons, in particular professionals and craftsmen from traditional architecture, is very important.

In the best cases, the church still stands and one or another photo of its construction has been found in archives in Europe. We have proven that the collaborative method between European and Chinese scholars not only generates new architectural knowledge, but also contributes to safeguarding threatened transcultural heritage and memories through material analysis and accurate heritage value assessments (Coomans & Xu 2017).

The present study of Xinjiang Cathedral is part of the collaborative program between the School of Archeology and Museology of Peking University, and the Department of Architecture of the Faculty of Engineering Science of KU Leuven, which has been developed since January 2014 and, among other things, resulted in the First International Forum on Sino-European Building Archeology in Beijing in 2016 (Coomans, Xu & Zhang 2019).

The archives of the Dutch Franciscans are conserved at the City Archives of Utrecht and contain a small section on China (Beck 2005: 1244). The most precious source on Xinjiang is an unpublished compilation written in 1985 by Father Constans Kramer (Kang Jimin 康济民, 1903–1998), the former bishop of Lu'an, entitled *The Kiangchow Story: The Dutch Franciscans in South-West Shansi (1936–1954)*, and a series of five pictures of the cathedral's construction works (Figs 3–7). This was enough to organize a field school (17–21 June 2019) on modern architecture for studying Xinjiang Cathedral with about 20 third-year undergraduate students from the building archeology program of Peking University.

4 DESIGN AND STYLE OF THE CATHEDRAL

Saint Andrew's Cathedral of Xinjiang is south-north oriented, with its main entrance facing south, according to Chinese rules of geomancy (fengshui 风水). The monumental brick Western-style façade with three portals and two spired towers 36.75-m high dominates the city. Unexpectedly, the plan of the cathedral is a single nave of eight bays ending with a polygonal 5/8 apse (Figure 2 plan). The 41.50-m long and 12.60-m wide inner space is punctuated with transversal arches resting on engaged columns along the walls (Figure 14). Each bay is covered with a lath and plaster groin vault with painted fake ribs. The arches reach a height of 13.30 m and the vaults about 14.50 m (Figure 2 section). There are no aisles, transept or ambulatory. Therefore, the very homogenous main space offers a good view of the main altar and is not disturbed by the side chapels and the sacristy that are annexed along the sides of the nave and the apse. Two polygonal radiating chapels open onto the 45° bays of the apse, which is an original way of placing side altars in a church without transept. The two straight bays of the sanctuary are flanked with rectangular secondary rooms: the Bishop's Chapel to the east and the sacristy with its back entrance to the west. There is a tribune for the choir above the sacristy. Seen from outside, one might think this volume is a transept under a transversal saddle roof (Figs 8 and 11), but inside there is neither a transversal space nor a crossing.

Further on, the nave is flanked with four almost square side chapels, two on each side, alternating with three bays with windows that directly illuminate the nave. The two square towers flank the first bay at the reverse of the façade: the south-west one contains the stair leading to the roof; the south-east one was the place of the baptistery. The interior of the cathedral is Romanesque style, characterized by round arches (all enhanced by voussoirs painted in alternating colors), triplet windows and Romanesque capitals (Figure 14).

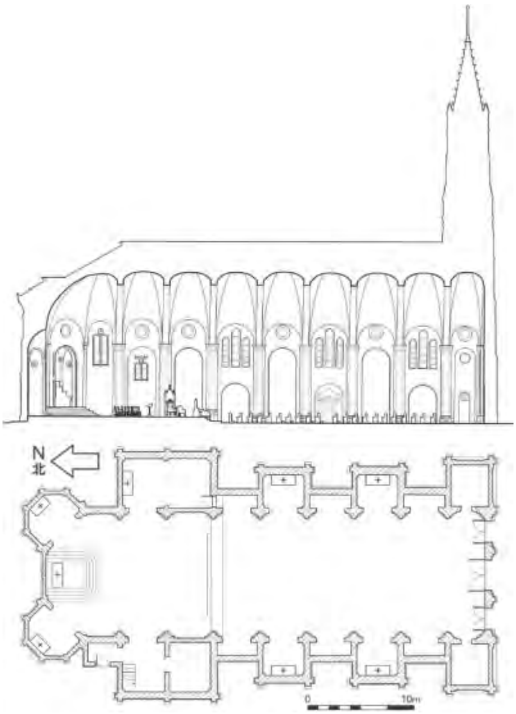

Figure 2. Xinjiang Cathedral, ground plan (south is to the right) and north-south section (© School of Archaeology and Museology, Peking University 2019).

The exterior of the cathedral, with its side chapels jutting out on the east and west flanks, has an unusual volumetry. A particularly intriguing element is the existence of an upper floor above the side and radiating chapels, whose blind windows and pediments rise as high as the walls of the nave (Figure 1).

The eclectic Western style of the cathedral mixes elements from Romanesque, Renaissance and Gothic architectural vocabularies. The exterior homogeneity is the result of the systematic use of brick as well as the high quality of the wall decoration made of molded bricks, shafts, capitals, arches, buttresses, blind windows and floral patterns (Wang & Feng 2019: 151–156). The Chinese roof tiles contribute to this overall harmony. On the main façade, Chinese and Latin dedication stones mention the year 1937.

5 CONSTRUCTION OF THE CATHEDRAL

Prior to being appointed apostolic prefect of Xinjiang, Father Pessers was, from 1929 to 1936, the pastor of Lu'an Cathedral and the procurator of the apostolic vicariate of Lu'an. The procurator was in charge of the physical organization of the diocese and was notably responsible for the construction, maintenance and financing of churches, schools, residences and other buildings. Since there was no church in Xinjiang

Figure 3. Xinjiang Cathedral, earth-ramming works on the site, 1936 (© Het Utrechts Archief, 1224, 291/48).

Figure 5. Xinjiang Cathedral, carpenters lifting a roof truss in the nave, 1937 (© Het Utrechts Archief, 1224, 291/45).

Figure 4. Xinjiang Cathedral, stone carvers at work, 1936. Note the city wall in the back (© Het Utrechts Archief, 1224, 291/49).

Figure 6. Xinjiang Cathedral, masons at work on the south-east spired tower, 1937 (© Het Utrechts Archief, 1224, 291/46–47).

worthy of becoming a cathedral, Father Pessers immediately built a larger one than that in Lu'an. He "used the experience he had gained in his many building activities in the Luanfu district, and he put the work into the hands of the same family of builders and artisans, who had been building the churches there for generations" (Kramer 1985: 7). The missionaries had thus transferred Western architectural and technical knowhow to Chinese craftsmen, who formed a specialized team that worked for them. This explains why Xinjiang Cathedral, as we will see, belongs to a group of large churches with similar plan, construction characteristics and Western-style decoration.

Having cleared the land to the east of the old church and the fathers' residence, the ground had to be rammed according to an ancestral technique (Coomans & Xu 2016: 169–173). One old photo shows two groups of about 20 rammers at work: a huge stone with a flat bottom is attached to a trunk, which is lifted at arm's length by the men and, at the foreman's signal, knocked to the ground (Figure 3). The operation is repeated as many times as necessary to obtain an unshakeable base. In another photo, stone carvers are carving the rectangular blocks that were used for the foundation and plinth of the cathedral's walls (Figure 4). These bluestones came from Mashou Mountain 马首山, about 25 kilometers from Xinjiang, where stone carvers' villages are established for generations (Wang & Feng 2019: 155).

A third photo shows an inner view of the nave under construction (Figure 5). The brick walls are completed and a heavy roof truss is standing obliquely in the middle of the nave, waiting to be lifted. This Western truss has the shape of a letter A and is made of two rafters, a collar and a king post. Wrought iron cramps fix the top of the rafters to the king post and the middle of the rafters to the collar. We will see later why this truss has no tie beam.

Two other photos of the works show masons on scaffolding raising the spire of the southeast tower (Figure 6). The roofs of the side chapels are covered with tiles. The last two old photos are a general outer view of the completed church (Figure 1) and an inner view of the nave without decoration but furnished with altars, a communion rail and cushions for the faithful in the nave: women on the left, and men on the right (Figure 7).

Apart from the sentence about Father Pessers and this remarkable series of photos, there is no information about the architect, the number of workers, the financing and construction costs, the impact of war on the works, and so on. It seems, however, that both

Figure 7. Xinjiang Cathedral, view of the nave to the north after completion, 1940 (© Het Utrechts Archief, 1224, 291/50).

materials and construction techniques were local and traditional. Neither the photos, nor building archaeological analysis suggest the use of rebar or concrete, at that time unaffordable in places like Xinjiang. In the late 1930s, these modern materials were only available in the treaty ports and places along railroads and great rivers like the Yangzi – which was not the case of Xinjiang.

6 CHINESE ROOF, WESTERN TRUSSES AND INGENIOUS BUTTRESSING SYSTEM

From a construction perspective, the two most interesting features of Xinjiang Cathedral are its large vaulted nave and the volumes of the side and radiating chapels that rise as high as the nave. Here we will see that both are structurally related.

The main roof structure of the nave is made up of eight trusses already described above (Figure 5). The trusses have no tie beam because their lower part includes the transverse arches of the nave. These arches are not made of brick but of lath and plaster, like all the vaults, according to a technique common in China (Coomans 2016). In the space between the trusses, the vaults of the nave rise about 1 m higher than the transverse arches and hang from the purlins, which have big round sections. This means that the vaults are light but the roof frame is robust to withstand the heavy load of the Chinese tiled roof.

The hybrid roof is thus made of Western trusses bearing a beautiful Chinese traditional roof covering. The purlins carry a floor covered with a layer of about 10 cm of earth mixed with lime on which lines of convex semi-cylindrical tiles are assembled with mortar, alternating with small vertical canals made of slightly concave overlapping tiles (Figure 8). The slope of the roof is low (30°) and the span of the trusses is wide (12.65 m). In short, under this weight, the pressure of trusses on the side walls is strong and buttresses are required because there are no tie beams.

Since there are no aisles, it was easy to buttress the nave and the apse. However, instead of classical buttresses, the architect designed side chapels whose transverse walls act as a buttressing system. This solution is ingenious and all the more effective as the walls of the side chapels rise to the same height as the walls of the nave and the apse (Figs 1 and 9).

Figure 8. Xinjiang Cathedral, roof of the nave and east side chapels, from the south-east tower (© THOC June 2019).

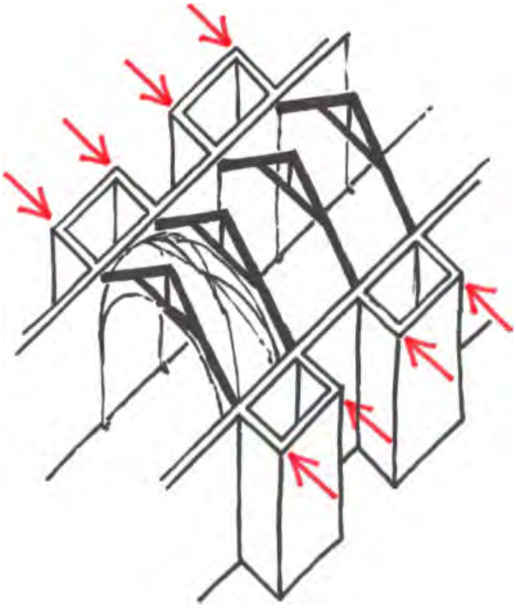

Figure 9. Xinjiang Cathedral, buttressing system of the roof trusses by the transverse walls of the side chapels (© THOC June 2019).

From a spatial-liturgical point of view, the side and radiating chapels did not need such a height because their vaults are much lower (8.60 m) than the side walls. What was the space above the vaults used for?

There are dark and empty spaces between the vaults of the chapels and the saddle roofs which cover them. The lath and plaster vaults of these chapels are light and exert no pressure on the walls because they are hanging on a sort of "mikado" of beams, the main ones of which are anchored in the walls (Figure 10).

Figure 10. Xinjiang Cathedral, Bishop's Chapel, east side of the nave, space and structure above the vaults (© THOC June 2019).

This type of carpentry looks like the backstage of a theatre.

7 MODELS AND SIGNIFICANCE

When doing fieldwork in Xinjiang, we were told that the unusual plan of the cathedral, with its single nave, side chapels and two radiating chapels, resembles the Chinese character *yang* 羊 (Figure 11), which means sheep/goat/ram and could refer to the Christian *Agnus dei*, the Lamb of God (*gaoyang song* 羔羊颂).

This poetic interpretation is also reported in recent literature (Wang & Feng 2019: 151) but is not attested to by old documents, to our knowledge. However, the relationship between Chinese characters and the shape of certain buildings is not unknown in Chinese architectural culture (for instance the characters 人 *ren*/ person/people; 中 *zhong*/ middle, and so on) The speedy construction of the cathedral's shell (in one year) suggests that the builders and craftsmen were familiar with this type of modular structure. Their model was the cathedral of Lu'an. Father Pessers "lets his confreres in Luanfu know that [his cathedral] was to be one meter longer and it would get one tower more than their own cathedral" (Kramer 1985: 7).

Lu'an Cathedral, built in 1903, was demolished in the 1960s but old pictures allow a comparison with Xinjiang. Both had a similar plan and structure with a single nave and the same display of side chapels, the radiating chapels excluded. However, Lu'an was pure Gothic, had a completely different façade and its single tower was located behind the choir (Figure 12). Inside, all the arches were pointed (Figure 13). Based on this model, at least two other smaller churches were built in southern Shanxi in 1930 at Fenyang 汾阳 and in 1932 at Jiucun 酒村. These two churches predate the cathedral of Xinjiang a little but may well have been erected by the same builders and craftsmen. Both have richly decorated Gothic-Romanesque style facades without towers. The parish church of Jiucun is particularly similar to that of Lu'an, including its campanile (Wang & Feng 2019: 148–151, 241–247, 299–301). Having defined this group of four churches, it remains to wonder about the use of European styles and models which together raise the central question of the modernity of Xinjiang Cathedral.

Figure 11. Xinjiang Cathedral, vertical view showing the *yang* 羊 shape of the building (© School of Archaeology and Museology, Peking University 2019).

Figure 12. Lu'an Cathedral under construction, view from the south-west, 1903 (© Het Utrechts Archief, 1224, 289/4).

Since the mid-1920s, the Holy See had stimulated a new missionary thought and strategy based on inculturation. The rejection of European styles in favor of the Sino-Christian style was part of the strategy to Sinicize church architecture (Coomans 2017). This new style does not seem to have penetrated the dioceses of South Shanxi, either because the Dutch bishops were conservative or because Chinese Christians claimed the foreign identity of their religion (Coomans, 2021b).

In Europe, however, elaborate Gothic Revival had been rejected after World War I and replaced by Romanesque and Byzantine references as well as

Figure 13. Lu’an Cathedral, inner view of the nave with furbishing, around 1930 (© Het Utrechts Archief, 1224, 289/6).

modernist reinforced concrete and simplified modern Gothic churches. A facade like that of Xinjiang Cathedral would no longer be built in Western Europe in the late 1930s and would have been considered conservative there.

Conversely, the interior space of the cathedral with its 12.60 m large single nave fitted perfectly with the architectural trends promoted by the Liturgical Movement since before World War I (McNamara 2009: 171–185). The idea was to bring the whole congregation together in a unified space without any visual obstacle between the faithful and the altar. In Europe, the use of reinforced concrete facilitated the construction of large covered spaces. This was not possible in South Shanxi before the 1950s, because this region was too remote and poor.

8 CONCLUSION

Xinjiang Cathedral was thus well and truly “imposing and provocative, on the highest spot of the city”, as in the words of Father Kramer (Kramer 1985: 7). And so it was certainly perceived by a large majority of Xinjiang’s citizens. The monumental “face” of the cathedral with two Gothic spires (Figure 15) was a foreign religious identity statement on the skyline of the historic city, and created a visual conflict with the pagoda of Longxing Temple 龙兴寺 (He 2016: 50–55). It was undoubtedly considered by many as a threat to the city’s harmony and good *fengshui*. As often happened after 1900, Western-style churches were erected in highly visible places as part of a spatial strategy (Coomans 2021a). This is in line with the wishes of Father Pessers, who was commissioned by the Holy See to develop a new diocese in South Shanxi following in the footsteps of the 17th-century Jesuits. At the same time, using the available construction techniques Father Pessers’s cathedral successfully created a modern liturgical space for the Chinese congregation which would have been boosted by the feeling of belonging to the universal Church (Figure 14).

Figure 14. Xinjiang Cathedral, single nave space, view from the south (© THOC June 2019).

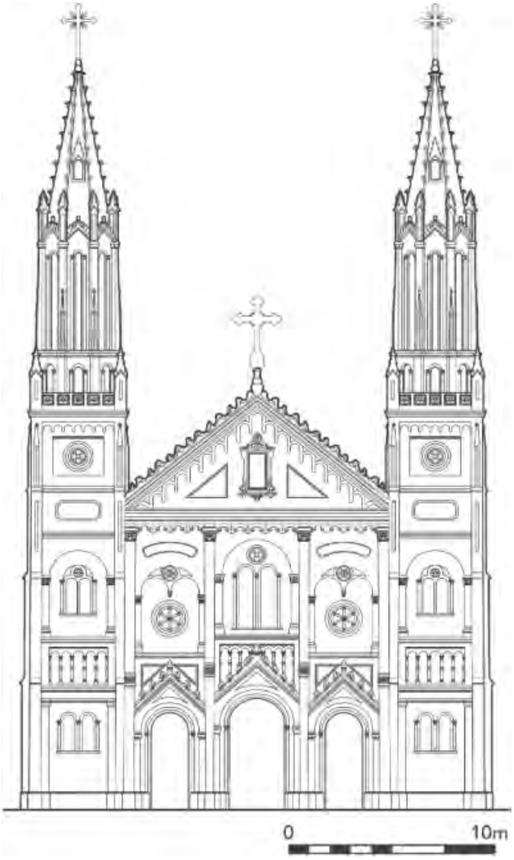

Figure 15. Xinjiang Cathedral, elevation of the south façade, (© School of Archaeology and Museology, Peking University 2019).

As the last Catholic cathedral to be completed during foreign missions, Xinjiang Cathedral is a milestone in the history of modern architecture in China. It was listed as a city monument on 15 November 2004 and a provincial monument on 6 June 2016.

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History of Construction Cultures – Mascarenhas-Mateus & Paula Pires (eds)

1950s housing in Milan: Façade design and building culture

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ABSTRACT: During the 1950s, the private residential sector breathed life into Milanese everyday building practice thanks to architects who were the exponents of a cultured professionalism that has rarely been examined in the most well-established historiography traditions. We consider this production to be the avant-garde of an everyday Milanese modern construction laboratory. Taking into account the evolved Milanese cultural context in which there was effective collaboration between designers, builders and producers, this paper gives a summary analysis of 15 buildings (almost all for mixed use) built between the end of the 1940s and the 1950s which are representative of recurring approaches to façade design. The analysis is conducted on the basis of some key construction elements of the façade project (claddings, windows, prefabricated panels), considered for their technological and figurative value, with reference to the historical technical literature (reviews such as *L'Architettura*, *Vitrum*, *Alluminio*, *Cantieri*, *Domus*, *Casabella* and manuals) and more recent studies on Milanese residential architecture of the 1950s.

1 INTRODUCTION

After the World War II, the vanguard of the debate on programmes and construction techniques for the national recovery developed in Milan involved designers, builders, manufacturers, and both public and private clients. In the housing sector, at least three factors characterized the Milanese real estate market. First, the birth of economic residential building districts in peripheral areas to accommodate migratory flows from southern Italy. Second, the development of mixed buildings (residence, offices, and small commercial spaces) and, lastly, the demand for luxury apartments in central areas of the city. The private residential sector breathed life into everyday building practice and, gradually, houses designed by architects such as Mario Asnago & Claudio Vender, Vito & Gustavo Latis, began to appear. These architects were exponents of a cultured professionalism rarely examined in the most consolidated historiography, although their work has recently been revaluated (Bettini 2016; Capitanucci 2007; Gramigna & Mazza 2001; Gurrieri 2008; Pierini & Isastia 2017). With the term cultured professionalism, we refer to the work of little known Milanese architects who applied a balanced synthesis between building practice and attention to domestic and international cultural theoretical debate, whose themes they came into contact with in their everyday practice. We consider the production of this cultured professionalism to be the avant-garde of an everyday Milanese modern construction laboratory, where architectural and building research developed a system of realization that became widespread in the city (and not limited to landmarks) and whose effects were more evident than in the rest of Italy.

This paper considers the evolved Milanese cultural context in which there was effective collaboration among designers, builders and. Starting from this premise, it gives a summary analysis of 15 buildings (almost all for mixed use) built between the end of the 1940s and the 1950s and representative of recurring approaches to façade design. These design techniques concerned the buildings in the following locations: via Broletto by Luigi Figini & Gino Pollini (1949); Condominio XXI Aprile (1951–53) via Velasca (1950), piazza della Repubblica (1954–55) and Corso Sempione (1961) by Asnago & Vender; the apartment blocks on via De Amicis by Vito and Gustavo Latis; via Lanzone (1951–52); and viale Montesanto by Vito Latis (1951–52); via Solferino (1950–51) by Gigi Ghò; via Marchiondi by Anna Castelli Ferrieri, Ignazio Gardella and Roberto Menghi (1951); via Calvi (1950–51) by Gianemilio, Piero and Anna Monti; viale Gorizia (1950–51) by Marco Zanuso; via Fatebenefratelli (1952) by Giulio Minoletti; and via Quadronno (1956–62) and San Siro by Angelo Mangiarotti (1956–59).

All the buildings were of different heights ranging from six to ten floors (with the ground floor intended for shops and, in many cases, the first two-three floors destined for offices), with reinforced concrete structures cast on site, external brick walls (sometimes with thermal insulation), and different types of claddings and façade finishes.

Analysis of the construction features confirms attention to the design of the façade, as indicated in recent studies conducted on Milanese modern architecture as proof of a domestic space project approach extended to the public dimension of the street and then to urban space design (Pierini & Isastia 2017).

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The analysis in this paper looks at some key construction elements of the façade design (claddings, windows, prefabricated panels), chosen for their technological and figurative value. The sources used so far have concerned historical technical literature (reviews such as *L'Architettura*, *Vitrum, Alluminio, Cantieri, Domus, Casabella,* books and manuals) and more recent studies on Milanese residential architecture of the 1950s.

2 ARCHITECTS, BUILDERS, MANUFACTURERS AND TECHNICAL REVIEWS: THE ACTORS IN THE MILANESE EVERYDAY LABORATORY

As indicated by various research studies, Milan represented a unique case in the Italian construction landscape of the 1950s due to a healthy collaboration among the different actors in the design and construction process (Irace 1996; Poretti 1997). In the city, as in the 1930s, cultural, economic and production conditions promoted a progressive transfer of technological advances from landmark works to the everyday building laboratory. This spirit established Milanese technological leadership comparable to Rome and other industrial areas of Northern Italy, such as Turin.

Well-known architects and younger architects who emerged in the 1930s breathed life into the lively Milanese laboratory, sharing a cultural background similar to that found in other European contexts. These designers had a good knowledge of both materials and their characteristics, a typical feature of a polytechnic education. Almost all of them were members of the Movement of Studies for Architecture (MSA) founded in Milan in 1945 with the aim of connecting the modern cultural experience of the 1930s with post-World War II reconstruction (Dulio & Rossari 2009).

They worked in small offices and were architects who were "aware of construction", more "builders than designers" (Gorio 1957). Despite the influence of real estate speculation, they could count on the collaboration of a network of traditional builders, with polyvalent and polytechnic labour, which allowed control of all construction processes, almost entirely based on work on site. Architects and builders were faced with the residential and service demand in areas of the historic centre and in the 19th-century fabric of the city, driven by the expanding industrial bourgeoisie seeking to legitimize its socio-economic role through an urban scenography renovated in both materials and aesthetical features.

The approach of the Milanese context was favoured by the combined activity of research institutes on innovative materials and technical reviews. These promoted information and updating for designers and builders through the publication of repertoires and technical notes, as well as reviews of Italian and foreign projects. This apparatus of scientific dissemination in the technological and manufacturing sector forged the unique nature of Milan in the Italian context and confirmed the tradition in the field of technical handbooks that had existed in the Lombard city since the 1930s (Griffini 1932; Pagano et al. 1934).

After the war, historical reviews such as *Casabella* and *Domus* restarted, while others such as *Cantieri* and *Vitrum*, were founded with the aim of disseminating technical knowledge on glass manufacturing processes, and on the use of prefabricated products. *Alluminio*, the review founded in 1932 by the Istituto Sperimentale dei Metalli Leggeri, reopened to spread knowledge on the use of light alloys, manufacturing techniques, anodizing processes of the profiles, requirements of plastic seals and on the types of windows. *Vitrum: lastre di vetro e cristallo*, was the review published as of 1949 by the Centro Informazioni e Studi per le applicazioni del vetro nell'edilizia e nell'arredamento. The review presented the use of glass products in building construction, industrial design and applied arts with an approach that favoured the aesthetical value of creations and of the material and products in the various fields of arts and industrial production.

This cultural *milieu* took advantage of the activity of the Milan Trade Fair, which restarted in 1947 with the reconstruction of the pavilions destroyed by the war, offering designers, builders and companies the opportunity to promote and learn about new materials, products and techniques (Greco 2012).

The Milanese designers profited from production companies that had their headquarters in Lombardy. For example, the major producers of metal frames and curtain walls were involved in the evolution of the design and construction process, as shown by the cases of Greppi, Alsco Malugani, Bombelli and FEAL (Fonderie elettriche alluminio e leghe). In fact, their design departments collaborated with architects in the preliminary stages for the main works. Companies such as Fratelli Feltrinelli, Colombo and Clerici, Conti Giovanni, who had specialized in the production of sash windows in the inter-war years (considered an emblem of rationality and modernity) confirmed Lombardy's leadership in the production of wooden doors and windows.

In the field of claddings, it is worth mentioning the Industria Ceramica Piccinelli of Bergamo, which started the production and marketing of clinker in Italy in the 1930s under the name of *Litoceramica*; it was subsequently joined by the Litoclinker and Italklinker brands, which were advertised on reviews and at main exhibitions. It is also worth mentioning the Società Ceramica Ferrari of Cremona and the Ceramica Joo of Milan, which in the 1950s produced tiles designed by Gio Ponti.

3 FAÇADE DESIGN AND BUILDING CULTURE

As observed in some of the most recent studies on residential Milanese architecture of the 1950s (Bettini 2016; Gurrieri 2008; Pierini & Isastia 2017), the *fil rouge* that united the houses of Figini & Pollini, Latis, Minoletti and Asnago & Vender was the care taken over façades, defined through design and functional schemes distilled by architects according to common canons.

The architects sometimes worked with the façade as a neutral field in which choices of standardization of the windows was applied. In other cases, they favoured a calligraphic approach, based on the aesthetical and construction relationship between the structural frame and the infill walls. Finally, they considered the façade as a continuous facing to be organized with openings placed according to expert construction and figurative devices.

The relationship between the window opening and the frame was different: sometimes the frame was advanced into the window opening, elsewhere it was set back. In other cases, screens and balustrades were integrated into the window design.

Finally, in some buildings, the insertion of "exceptional episodes", such as bow-windows or loggias, helped the architects to give depth to the façade and create light and shadow (Bugatti & Crespi 1997, Buratti 1990).

The relationship between the structural frame and the infill walls was a key element of the Italian experience of those years, but it was developed differently in the two cultural poles of the country (Rome and Milan). Roman construction realism, expressed by Mario Ridolfi in the towers of Viale Etiopia (1950–54), was flanked by the more sober tones of the Milanese façades. In this second experience the more essential style and the sometimes-abstract intonation of the aesthetical layout, pursued through the treatment of windows and claddings, testified the greatest influence of the building industry (Poretti 1997).

In the houses of Vito and Gustavo Latis, the structural frame often guided the design of the geometric grid in which the loggias (as in the house on via De Amicis) were inserted, elsewhere it was concealed with the use of balconies and metal grids which were placed further forward than the walls, as in the houses on via Lanzone and on via Monte Santo by Vito Latis (Figure 1). The most abstract and geometric tones were in the houses of Asnago & Vender.

A unique experience, linked to industrial design rather than to building prefabrication, concerned the work of Angelo Mangiarotti, demonstrated by the houses on via Quadronno and in San Siro, presented with interest in *L'Architettura* and *Domus*. Even in this case the Milanese cultural *milieu,* enriched in the mid-1950s by the *Stile Industria* review directed by Alberto Rosselli and by the *Association for Industrial Design* (ADI) influenced by the Ulm school, affected Mangiarotti's approach to the curtain wall design, considered by the Italian architect as an industrial design object.

In addition to the essential technical information on *Vitrum*, *L'Architettura* and *Domus*, the construction characteristics of these buildings were presented on the *Antologia di edifici moderni in Milano* by Piero Bottoni (1954) and in *Nuove architetture a Milano* by Roberto Aloi (1959), which specified techniques, materials, and products, indicating a construction awareness typical of this generation of architects.

Figure 1. Building in via Monte Santo by Vito Latis, 1951–52. Source: Aloi 1958.

Figure 2. Building in via Gorizia by M. Zanuso, 1950–51. Source: Bottoni 1954.

The designers selected stone and ceramic claddings, worked the concrete when exposed, elaborated accurate details of connection between materials and components. Furthermore, the designers collaborated with painters and sculptors, as demonstrated by Marco Zanuso's house on viale Gorizia in which the architect worked together with the artist Gianni Dova to decorate the front (Figure 2) and the house on via Lanzone by Vito Latis in which the sculptor Lucio Fontana inserted plastic-coloristic decorative elements. This approach shows that "the Milanese houses choose, through the rich collection of building systems and materials used, not to follow the line of continuity of orthodox modernity" (Pierini & Isastia 2017), with the result of the Italian cultural community being closer to the experience of the Modern Movement as of the 1930s.

This repertoire of construction choices included claddings, windows and, sometimes, prefabricated panels as essential elements of the façade design. Therefore, we decided to investigate and compare the use of these elements in the 15 buildings studied, to understand their common features and identify the effects on the Milanese building culture of the period. The investigation sought to enrich the analysis developed by Italian architectural historians in recent years with considerations regarding recurrent materials and construction techniques.

4 CLADDINGS: LITOCERAMICA, MOSAICS, MARBLE

Litoceramica (sintered ceramics) and mosaics were the preferred options in the repertoire of Milanese constructions examined in this study.

The use of *litoceramica* in Milan spread for the first time in the main works of Giovanni Muzio (Malugani house and Bonaiti house in 1935), becoming a reference product for post-war designers; the Asnago & Vender buildings on via Velasca and the Condominio XXI Aprile are testament to this, where *litoceramica* was used together with marble to distinguish the various parts of the building (in the Condominio XXI Aprile, marble covered the block of the offices and clinker was used for the tower accommodating the houses).

The mosaic, with ceramic and glass-based mixtures worked into small pieces of different geometry and colours to be applied with mortar, was acclaimed by Gio Ponti in *L'Architettura* in 1941 as a "perfect" material for modern architecture (Bernardini 2017). In the residential sector it was widely used in the 1950s both in Rome and in Milan, first in main works such as the "Il Girasole" house in Rome (1947–50) and in *case albergo* (1949–5), the office and housing complex in Corso Italia (1952–56) in Milan by Luigi Moretti, as well as in the office and residential building in via Melchiorre Gioia in Milan (1950–52) by Pietro Lingeri.

Subsequently, the 2 × 2 cm tiles were adopted for finishing the walls of many residential buildings in Milan (apartment blocks on via Colonna and on via Plutarco by Asnago & Vender, in via Cassiodoro by Roberto Morisi, on via Moscova by Ezio Sgrelli, on corso Sempione by Gianemilio, Piero & Anna Monti, on via Montesanto and on via Turati by V. Latis,) as well as in Rome, with their use also spreading to southern Italy in the 1960s.

Figure 3. Building in via Velasca by Asnago & Vender, 1950. Source: Bottoni 1954.

5 WINDOWS, BOW-WINDOWS AND LOGGIAS

Gio Ponti wrote that "The mysterious game of architecture begins with the window", alluding to the different composition techniques concerning the size, geometry, and technology of windows (Ponti 1957).

The relationship between window and wall was fundamental in the design of the façades of the Milanese houses of those years, with different configurations. In some examples the bow-windows favoured the effect of a "folded sheet" of the façades, as evidenced by the building on corso Sempione by Asnago & Vender, the one on Viale Montesanto by Latis and the house on via Marchiondi by Ferrieri, Gardella, Menghi. In other cases, the position of the windows varied with respect to the wall (advanced or set back), as evidenced by the Condominio XXI Aprile and the house on via Velasca (1950) by Asnago & Vender (Figure 3), an example of those "Architectures that make a picture" written about by Raffaello Giolli (Giolli 1943).

From a construction point of view, the window frame was one of the characterizing elements of the design of façades of the analysed buildings. In Italy in the post-war period, to support the housing demand and the construction of public housing programs the UNI (Italian National Unification Agency) favoured the unification of doors, windows and balconies, referring first to wooden frames (Ed. 1950).

The use of standard elements was also promoted by post-war handbooks, as evidenced by Mario Ridolfi's work on the unification of windows and doors, published in the *Manuale dell'Architetto* by the National

Research Council (1946). As evidenced by the technical notes of *Vitrum* and *Alluminio*, Milanese residences of the 1950s preferred casement windows (for smaller openings) and sliding windows with metal or wooden frames. The sash window facilitated movement, cleaning, and maintenance.

The most advanced solution, which marked the studied repertoire, was the sliding window. This large element, destined for living rooms and in direct contact with loggias and terraces, was characterized by the use of thin frames that allowed wide panoramic views. Sliding windows were initially affected by air tightness problems, which were subsequently corrected with the use of gaskets and felts and, in some cases, with the revision of the sliding guides.

For example, Sergio Pedrazzini's patent, presented by *Vitrum* in 1951 and applied in some of the Milanese buildings, was distinguished by its use of coplanar leaves and a good rebate on the sides of the sliding leaf, influencing both the aesthetic features and the technological requirements of the product. The sliding leaf – thanks to a special shaped guide – shifted with a double movement, the first advancing the leaf forward and the second gliding it horizontally (Ed. 1951).

The technology of the frame was affected by developments matured in the 1930s. The metal frame used in the 1950s derived from the diffusion of the so-called *ferrofinestra* frame, with a thin section, recurrent for smaller windows and frequently reserved for façades not exposed directly to the street.

The aluminium frame – although it represented only 2% of window production at the beginning of the decade in Italy – was the most promising evolution, frequently used in office buildings. It was also selected by some designers in the residential field. Promoted by *Alluminio* for aesthetic reasons, lightness, ease of maintenance and good air tightness, it was initially reserved for the most prestigious buildings, with an estimated cost at the time of 15,000 ITL (Italian lire) for a simple window and of 30,000–40,000 ITL for a more advanced window, with an incidence of between 6% and 9% for an area of 18–25 square metres and an illuminating ratio between 1:6 and 1:7 (Goldstein-Bolocan 1952).

In cases of greater attention to construction, double glazing was used, as testified by the windows with anodized aluminium and oak wood frames in the office and residential building by Asnago & Vender in via Velasca, in that by Gigi Ghò in via Solferino and in the house in via Fatebenefratelli by Minoletti. Securit tempered glass was typically used for larger windows in communal areas of the buildings.

In the Condominio XXI Aprile and in the office and residential building on via Lanzone by Asnago & Vender, we note the use of double windows that defined a buffer space intended as a greenhouse-garden for the apartments (Figure 4). This approach typically concerned large horizontal windows in which the external parts had anodized aluminium frames while the internal ones had wooden frames with double glazing.

Figure 4. Condominio XXI Aprile by Asnago & Vender, 1951–53. Source: Aloi 1958.

The use of the loggias, as evidenced by the house in via Broletto by Figini & Pollini and that by Latis in via Lanzone, constituted a useful solution to protect the windows from direct contact with rain and solar radiation, to shade inhabited spaces and provide living rooms and/or outdoor services. Loggias were sometimes combined with the use of screens to increase protection and privacy. In the house on via Broletto, there were concrete honeycomb gratings used as parapet and screens (Ed. 1949).

6 ANGELO MANGIAROTTI AND THE PREFABRICATED FAÇADE

The diffusion of prefabricated elements in the residential field slowly developed in Italy starting from the early 1960s with the importation of French prefabrication systems (Barets, Balency, Coignet, Camus) mainly by the IACP of Milan (Istituto Autonomo Case Popolari).

Italian architects, even those closest to building industrialization, were not interested in prefabrication, despite the theoretical debate of the post-war period (Greco 2020). The Milanese architect Angelo Mangiarotti was an exception. Well known above all for the construction of prefabricated industrial buildings, in the 1950s he designed two houses in Milan using prefabricated façade panels. Trained at the Ulm School directed by Max Bill, he shared the aspiration to respond to the new needs of a highly industrialized society through scientific knowledge, the matrix approach and the use of diagrams as analytical tools to manage the issues of seriality, repetitiveness and randomness as arguments of architectural composition.

Mangiarotti was passionate about the flexible use of prefabricated façade components to manage the process of user participation in the project. In fact, industrialized prefabrication, and user participation (involved in the design of the interior spaces, with the free arrangement of internal walls and of windows on the façades) were themes that coexisted in Mangiarotti's design process. The house on via Quadronno and the one in San Siro, designed by the Italian architect with Bruno Morassutti, had an articulated plan which corresponded to a unitary layout of the façade composed of opaque modular panels and wooden window panels (Ed. 1963). All components, connected to the reinforced concrete slabs to allow internal flexibility and the articulation of the façades, were freely arranged on the various floors, according to the functional needs of the users.

7 CONCLUSIONS

Ultimately, the originality of the Milanese building laboratory was supported by both the cultural spirit dating back to the 1930s concerning the work of technical reviews and cultural associations, as well as by the advanced socio-economic *milieu* that favoured the network of manufacture.

The experience presented in this paper involved a group of architects who designed a total of almost 100 buildings of the approximately 13,400 (residences and mixed buildings) built in Milan in the period between 1948–61 (Dulio & Rossari 2009). These are a small number of buildings which nevertheless contributed to the urban image of those years, as recent studies have indicated.

We believe that in terms of construction we can identify specific aspects related to a common approach to façade design. Unlike what typically happened in other European countries such as France and Belgium (Bullock 2007; Bullock 2008; Graf & Delemontey 2012; Van de Voorde et al. 2015), the walls of these buildings were built on site, with brick blocks and masonry bricks; concrete blocks and panels were not very common while light sandwich panels were absent. These characteristics link Milan to the rest of Italy and to a construction culture which was mainly based on on-site building techniques.

On the other hand, there were original elements that, starting from these buildings, spread throughout the city and, slowly, throughout Lombardy and other Italian cities (including those in southern Italy) in the 1960s: the use of colour in the claddings (plasters, mosaics and *litoceramica*), large sliding windows, aluminium frames and metal grids.

The materials and cladding techniques used referred to the modern repertoire developed in the 1930s. Their use was marked in the residential sector by the general conservation of masonry construction as the favoured option, even when updated in its completion and finishing systems (Poretti 2004). The combination of colours and materials, however, marked an evolution with respect to the heritage of the 1930s and differentiated the new buildings from the sober tones of the monochromatic walls of the interwar years.

These articulated solutions used by the architects to obtain a wealth of colours, materials and textures were affected by the organic approach of Northern Europe (use of colour, different material textures) according to a custom that differentiated this production from the contemporary Roman buildings (Buratti 1990).

The window frame was the most innovative construction element in the design of the façades of the buildings analysed. The metal frame used in the 1950s derived from the 1930s, but was updated after World War II, with the use of aluminium in the residential sector and care taken over water tightness and thermal insulation problems.

These choices, when adopted in other cities, characterized luxury buildings in the central areas, confirming the nature of a construction culture reserved for bourgeois urban residences. This relationship between construction features and socio-economic position of users made the Milanese experience studied comparable to the case of the *palazzina* that played similar role in Rome in the 1950s in defining a different building repertoire with typological and construction characteristics related to the Roman building culture (Lucente 2000).

On the other hand, the use of prefabricated panels proposed by Mangiarotti in his two Milanese houses is to be considered a unique experience. It is linked to the Italian designer's culture, but was not transferred to other contexts. Mangiarotti's two Milanese houses were examples of a "non-designed façade" (Ed. 1962), predisposed to continuous changes, which influenced two of Mangiarotti's subsequent projects: the apartment block in Monza (1968–75) and the one in Arosio (1974–78) (Graf 2015).

The basic rules were shared by the four buildings and highlighted the unique character of Mangiarotti's contribution to the Milanese scene and, more generally, to the Italian one; namely, his use of the prefabricated component in the residential sector as a design object that translated different ways to inhabit the domestic space in multiple geometric and figurative combinations.

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History of Construction Cultures – Mascarenhas-Mateus & Paula Pires (eds)

Technological development in the construction of Kasumigaseki Building: Japan's first super high-rise

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ABSTRACT: This paper focuses on the technological developments and characteristics of the construction of the Kasumigaseki Building (1968), Japan's first high-rise building with a height of over 100 meters. From an examination of survey documents, this paper explores the new technologies applied to the construction of the Kasumigaseki Building and their impact, particularly those that shortened construction time by process management and prefabrication. First, the general contractors managed the construction process by using the Program Evaluation and Review Technique (PERT) method as well as with the use of a mainframe computer, building every floor in six days. Second, to decrease the amount of lifting or connecting by bolts, the steel posts and beams were divided into special units. The general contractor also developed tower cranes and a new deck plate floor system, among other innovations. Although most of the technologies used in the construction of the Kasumigaseki Building have since been improved, the fundamental concepts such as process management are still in use today.

1 INTRODUCTION

1.1 *Background*

Japan has made unique advances in the construction of high-rise buildings since the elimination of the 31-meter height restriction in 1964. The Kasumigaseki Building (1968) was the first high-rise in Japan to exceed 100 meters in height. Several new technologies were developed in its construction, such as architectural design and structural engineering (Construction Committee of Kasumigaseki Building 1968). Following the construction of the Kasumigaseki Building, many high-rise buildings have been built, particularly in large cities such as Tokyo and Osaka, affecting the urban scenery and environment.

Technologically speaking, the Kasumigaseki Building is one of the first examples of steel-framed high-rise buildings in Asia. In addition, it is the oldest, high-rise building in earthquake-and-typhoon-prone areas in the world, after the Torre Latinoamericana (1956), among others (Mitsui Fudosan 2018).

In terms of construction technology, Japanese high-rise buildings are recognized for their characteristic developments such as robotic construction and automation. Several gigantic general contractors developed automated construction methods, including automated transportation and all-weather construction techniques that cover the construction site with a temporary roof (Bock & Linner 2016; Yoshida et al. 1997). These unique technologies were later abandoned after the bubble economy when the wages of laborers were high.

However, there are few studies of the history of high-rise buildings in Japan; neither are there many systematically-organized studies on construction. As a rare example, Kano (2009) described the brief history of construction technologies in Japan, including those used in high-rise buildings and other building types such as factories and stadiums. Yamazaki (2015) focused on hybrid structures, such as reinforced concrete and steel, to reduce the cost and duration of construction largely in the post-1980 period. Lifting and transportation are vital for the construction of high-rise buildings. Starting from the 1960s, there have been many trials related to lifting and transportation of high-rise building construction materials in Japan. In the 1990s, specialized subcontractors emerged, particularly for high-rise condominium construction (Gondo 2020; Matsumoto 1997).

It is well-known that various construction innovations had their origin in the Kasumigaseki Building or other high-rise buildings of the same era. Nikai, the construction manager of the Kasumigaseki Building, published several reports, including extensive construction data (Nikai 1969). A booklet commemorating the 50th anniversary of the completion of the Kasumigaseki Building summarizes various features and contains many photos of the construction (Mitsui Fudosan 2018). In addition, there were several attempts to apply Colten Steel and aluminum casting to curtainwall design, and these discussions were recorded and published, as well (Mitomo et al. 2018).

Compared to architecture in the heroic tradition, skyscrapers, in general, and their construction aspects

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are less well documented, and it is thus thought that both documental materials and testimony will become harder to collect in the future.

The primary purpose of this study is to clarify the characteristics of the construction of the Kasumigaseki Building. It also seeks to explain the comparative significance of the building within the context of the development of high-rise construction to date in Japan.

The method of this paper involves documentary research. There is an unprecedented amount of detailed data available on the construction of the Kasumigaseki Building. This paper focuses, in particular, on process management and prefabrication, both of which are vital aspects of reducing the construction time of high-rise buildings. All images and figures in this paper are reprinted from the Kasumigaseki Building's 50th anniversary Book (Mitsui Fudosan 2018).

2 OUTLINE OF THE KASUMIGASEKI BUILDING

2.1 *Background of the project*

Since the Urban Buildings Act of 1919, building heights in Japan have been limited to 31 meters (the equivalent of 100 *shaku*, the Japanese traditional module). This restriction is believed to be due to earthquake and fire considerations. In terms of steel-framed office buildings, the Marunouchi Building (1923) and the Mitsui Main Building (1929) were well-known examples of the early, steel-framed buildings in Japan, with brick or reinforced concrete walls (Committee for Architecture that supported modernization of Japan, 2019, 132–133). The steel frames of these projects were imported from the United States. In 1963, in response to urban densification and the development of structural theory, a floor-area ratio system was introduced. The first building to exceed 31 meters was the Hotel New Otani (1964), which involved the construction of a large building with 1,044 rooms in preparation for the 1964 Tokyo Olympics. The Hotel New Otani is also known as the first building to use unit (prefabricated) bathrooms with a washbasin, toilet, and bath. Subsequently, several buildings 60–70 m high were built.

The Kasumigaseki Building is 147 m in height and has 37 floors, a building that greatly surpasses in size of those previous built under 100 m (Figure 1). The developer, Mitsui Fudosan, and its president, Edo Hideo, planned the building for the Toranomon area of Tokyo.

2.2 *Characteristics of the Kasumigaseki Building*

The design of the Kasumigaseki Building is characterized by its "flexible (soft) structure." There had been controversy over flexible or rigid structures among Japanese structural engineers from the pre-war period. Based on the development of structural engineering and computers, Japanese structural engineers, such as Kiyoshi Muto or Ryo Tanabashi, developed the theory of flexible structure. Flexible structures are designed to absorb seismic energy, not to resist it through the use of rigid and heavy structures. In contrast, the thin pillars of the Kasumigaseki Building are laid out at 3.2-meter intervals on the periphery of the building (Figure 2). The overall weight of the building was also reduced. In terms of materials, high tensile strength H steel was developed by Fuji Steel. As opposed to the pre-war, steel-framed office buildings, the materials of the new, flexible buildings were made in Japan.

Figure 1. Kasumigaseki Building construction.

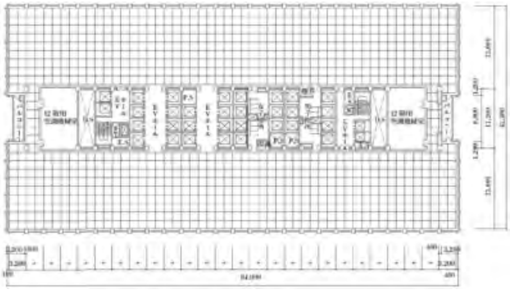

Figure 2. Plan of standard floor (12th floor).

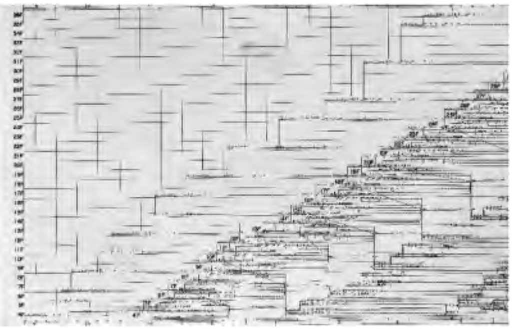

Figure 3. Network process chart.

The standard floor plan of the Kasumigaseki Building is lined with columns both on the perimeter and at the core (Figure 3). The longer span is 15.6 meters long. Densely aligned pillars give the sense of a flexible structure. The architectural design was created by Mitsui Fudosan and Yamashita Sekkei, and the construction company was a joint venture between Kajima Corporation and Mitsui Construction.

3 CHARACTERISTICS OF CONSTRUCTION

3.1 *Process planning and management*

3.1.1 *PERT*

The construction manager, Nikai Sei, described the essence of construction of the Kasumigaseki Building as the "continuous repetition of a standard floor" (Nikai 1972). In high-rise buildings, the standard floor is repeatedly constructed. In addition, high-rise buildings are often surrounded by vacant land, thus, the plan of standard floors are like well-formed rectangles. As a result, not only is the standard floor repeatedly constructed, but many repetitions are also found within the standard floor. This repetitive work can be shortened and further synchronized to maximize the capabilities of the many groups of laborers.

To be more specific, it was decided to construct each standard floor of the Kasumigaseki Building in six days. If the steel frame, deck plate, floor concrete pouring, piping, among other things, were constructed at the same pace, there would be no wastage in the construction capacity of each expertise. For example, if the deck plate takes seven days, the construction of the steel frame will proceed upward, but the floors without the deck plate will remain underneath it. If the deck plate takes five days, but the steel frame is not finished, the deck plate craftsman will have to take one day off every six days.

In addition to such synchronization, a new process planning technique – Program Evaluation and Review Technique (PERT) – was implemented, although it is unclear when PERT or networked schedules were first used in Japanese construction.

In 1957, the Soviet Union launched the world's first satellite, Sputnik 1, which sent shockwaves through the Western world. Although the incident forced the United States to dramatically accelerate the speed of its own development of missiles and rockets, the US did not know where to start in the vast process or where to concentrate its control. The logical solution to this problem was PERT, the network process chart. It makes it possible to logically derive critical paths that lead to delays in the overall construction period and floats that represent the margin period of a certain task.

In the Kasumigaseki Building, there were a total of 2,500 work units, which were assembled into a network schedule using a large computer, SERAC (Figure 3). After this overall schedule was created, the "collapse of the mountain" was performed. By knowing the days when workers were concentrated, the network process chart was used to level out the number of workers by shifting the work that floats to later dates (Figure 4). With such a detailed plan, a huge number of people, 455,000 in total manpower, were controlled from the start of the steel frame erection of the high-rise section.

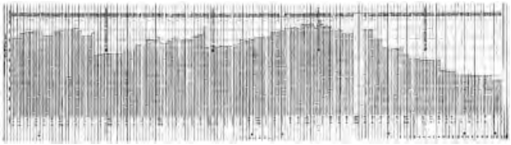

Figure 4. Collapse of the mountain.

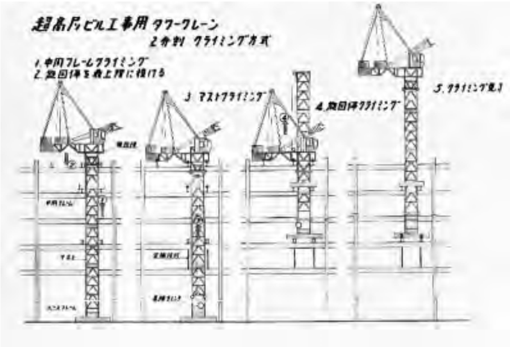

Figure 5. The diagram of tower crane.

3.1.2 *Lifting*

The tower crane used at the Kasumigaseki Building is characterized by the separation of the slewing body and the mast, in which the slewing body is fixed to the building frame while the mast rises through it. Instead of the swivel and mast climbing at the same time, the swivel is fixed to the body, which improves the stability and speed of the ascent (Figure 5). As a result, a climbing process that previously took about six days with the conventional Geideric crane was completed in only one day. In the Kasumigaseki Building, nine ascents were made during construction. In the Asahi Tokai Building (1971, 110 m high), the first skyscraper constructed by Shimizu Corporation, a hydraulic mechanism was used to climb the tower crane which was considered much safer and less time-consuming than the previous wire type of climbing. However, the separation system of the slewing body and the mast was the same.

After the Kasumigaseki Building, the capacity of tower cranes gradually improved. In the construction of the Kasumigaseki Building, the steel frame pieces were designed to be less than six tons per piece (six tons would allow the tower crane to lift a boom with a radius of 30 m, 200 t-m capacity). Subsequently, the lifting capacity of tower cranes was increased to 900 t-m during the bubble era, for example in the construction of the Tokyo Metropolitan Government Building (1990, 243 m high) and the NEC headquarters building (1990, 180 m high). In addition, the Yokohama Landmark Tower (1993, 296 m) used a very large tower crane with a capacity of 1,500 t-m. This increased the maximum lifting weight to 70 t, which made it possible to


Figure 6. Concrete conveyors.


Figure 7. The container and pallets.

lift a preassembled steel block unit on site to 65 t per piece.

As with the self-climbing tower cranes, a major productivity improvement was achieved in the pumping of concrete. When pouring concrete on a floor deck plate, transporting the concrete to the upper floors is a challenge. In the Kasumigaseki Building, the concrete, kneaded with a bacher plant, was lifted by a special elevator. Because the concrete was a hard consistency of slump 6, the bucket could not fall off even if it was tilted, so a hopper was used. In addition, for the horizontal transport of the weighted concrete, cat wagons (wheelbarrows) were used up to the 14th floor; in this instance, the productivity was low. Thus, the concrete conveyors were used to transport the concrete to the 15th floor and above (Figure 6).

In 1964, a self-propelled concrete pump truck was put to practical use, and, in 1966, a concrete pump truck with a boom was imported. In the case of the Yokohama Tenrikyo Church (1972, 102 m), the first skyscraper constructed by Takenaka Corporation, a concrete pump truck was already pumping directly to the top floor (slump 21). Gradually, as the capacity of concrete pumps improved, it became possible to pump relatively hard-milled concrete, and, in the Shinjuku Green Tower Building (1986, 109 m), slump 18 concrete was pumped up to the top floor. Recently, ultra-elevation pumping of lightweight concrete up to the top floor of the tallest building in Japan, Abenoharcus (2014, 300 m), was approved by the Ministry of Land, Infrastructure and Transport for slump 23 concrete. Parallel to the lifting technology, concrete injection technology was also improved with concrete-filled steel pipes (CFT).

During the 50 years since the creation of the Kasumigaseki Building, the system responsible for lifting has also continued to change. The types and amounts of materials to be lifted in high-rise buildings are enormous. Significant labor is required to manage these loads, for example determining which cranes and lifts are used to transport the materials. In the case of conventional low- and mid-rise buildings, each specialized company could use elevators and other equipment at their own discretion, but in the case of high-rise buildings, even if the materials are brought to the elevators at the desired time, they may have to wait for up to an hour.

Therefore, a move to centralize lifting management at a single location or assigning dedicated workers to handle the work was established. This kind of ingenuity in lifting management was already seen at the time of the Kasumigaseki Building. Kasumigaseki Building materials were classified into large (4.0 m and above), medium (1.8–4.0 m), and small (1.8 m and below) sizes. Cranes, cargo lifts, and elevators were used for each category, and small materials, pallets, and containers were used, in particular, to reduce the time and effort required for accumulation and unloading (Figure 7).

Around 1990, subcontractors began to communicate directly with each other about the plans for lifting without the engineers of the general contractors. Later, due to the sharp rise in labor costs and labor shortages during the bubble period, the disadvantages of having a specialized construction company's craftsman handle the entire process of lifting became significant, and it became common for specialized "lifting" companies to handle the lifting of high-rise buildings.

3.2 *Prefabrication*

3.2.1 *Steel post and beam*

The significant structural feature of the Kasumigaseki Building is its flexible structure that can flexibly absorb the sway of earthquakes; this is reflected in the method the steel frame is constructed. In the Kasumigaseki Building's elongated rectangular plan the H-steel columns are spaced at 3.2-m intervals in the longitudinal direction, and the beams that connect them are also unique. In steel construction, short beams called brackets are generally welded to the columns and delivered to the site. In order to connect the columns and beams with bolts, the bracket where the beams are attached is needed on the pillar side.

In the Kasumigaseki Building, these brackets are longer than usual, and the brackets on adjacent columns are joined directly to each other (Figure 8). This means that instead of the usual method of joining

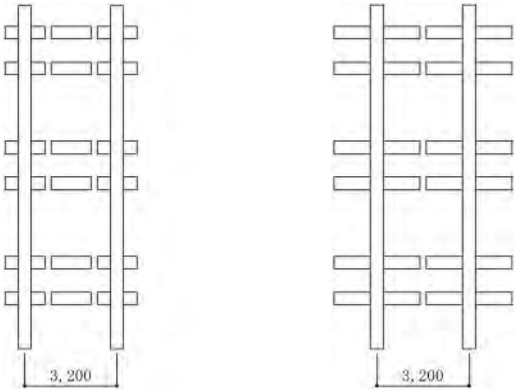

Figure 8. Steel Column and Beams (Left: conventional brackets and beams, Right: long brackets).

columns, that would require two joints between them (the two brackets to the beam), the brackets are joined together and only one connection is needed. Furthermore, if the columns with brackets are only lifted and the lifting of the beams is no longer necessary, the lifting time is reduced by the number of beams.

This difference is critical in a 37-story building with 26 spans of columns in the longitudinal direction. In addition, the columns in the Kasumigaseki Building are made of H-steel (nowadays, square steel pipes are generally used), and to reinforce the weak shafts and make the column supports thinner, a two-stage beam is used. If four beams, or brackets, are attached to a column (because of the two-stage beam), there are approximately 3,000 beams. By extending the brackets to form the beams, this lifting weight is no longer entirely necessary.

On the other hand, on the side where the large beams with a span of about 16 m are hung, brackets are not installed due to transportation efficiency issues, and pillars and beams are directly connected to each other. This “non-bra” system is often seen in today’s large building sites. The weight of the pillars is set to be less than six tons, based on the capacity of the tower crane.

3.2.2 *Honeycomb beam*

In the plan of the Kasumigaseki Building, the columns and beam system in the longitudinal direction were constructed in the method of longer bracket, but the columns and beams in the shortitudinal direction in the plan, which are orthogonal to each other, were also characteristic. Office buildings typically require a wide, continuous space. As the Kasumigaseki Building is used as rental offices, there are times when it is desirable to divide the large space into smaller spaces or to connect those smaller spaces to larger spaces. In the Kasumigaseki Building, the office space in the short side direction skips 15.6 m in span.

Normally, the longer the span, the higher the cross-sectional height of the beam, and the higher the cross-sectional height, the heavier each beam becomes. In the Kasumigaseki Building, emphasis is placed on weight reduction, so the architects and engineers wanted to avoid making the beams heavy. Reducing the weight of the beams can be achieved by making truss-like beams.

Figure 9. Honeycomb beams.

However, it takes time to make a perforated beam by welding or other means. The honeycomb H-beam was invented to solve this problem. A honeycomb H-beam is a beam with a hexagonal hole near the center of the web. The weight of the beam is reduced by the hexagonal holes that form a beehive, in contrast to the weight and strength of a steel beam without holes, because it is connected diagonally like a lattice beam. The holes can also be used for piping.

Honeycomb H-beams are also unique in their manufacturing method. First, an ordinary H-beam is manufactured. The web of the H-beam is then cut into zigzags. Then, one of the two T-beams is turned over and welded so that the peaks are in contact with each other. The two peaks are then connected to each other, leaving a honeycomb-shaped hole (Figure 9). This manufacturing method reduces the manufacturing time and increases the material yield. These longer bracket and honeycomb beams were also seen in photos of several buildings in the 1970s.

The connection between this honeycomb H-beam and the column is also ingenious. The honeycomb H-beam has a non-bracket construction method without brackets, as opposed to the long brackets omitted in the previous Figure of “Ki”. If a beam is attached to a column with a ki-shaped beam, the beam will protrude from the column in three directions, which will greatly reduce transportation efficiency. Therefore, a T-shaped plate, which serves as a gusset plate, is welded to the beam in advance, and then the flange of the column is tightened with high strength bolts.

3.2.3 *Horizontal piping unit above the floor*

An innovative development was also made for the toilets in the Kasumigaseki Building. Conventionally, horizontal pipes were embedded in the floor while vertical pipes went through the toilet floor vertically. In this system, whether vertical or horizontal pipes are used, in case of clogging, the pipes would need to be repaired or replaced by piecing together the finishing tiles or concrete floor. In addition, because the

Figure 10. Horizontal piping unit above the floor.

Figure 11. Linear Ceiling System.

Kasumigaseki Building is designed according to the flexible structure theory, pipes embedded in the floor and other structures could be damaged in the event of an earthquake (Figure 10).

Therefore, horizontal piping units above the floor have been developed (Figure 11) for the Kasumigaseki Building. The developed unit consists of horizontal pipes installed above the floor and connected directly to vertical pipes. This method eliminates the need for piping through the concrete floor or embedded in it. In addition, piping inside the unit simplifies installation by simply lining up the units and connecting them to the toilets and pipes. The sanitary ware manufacturers, Toyo Toki and Ina Seito, refused to manufacture the units because they did not specialize in plumbing, so Okamura Corporation, a furniture manufacturer, manufactured the units (although the company withdrew from manufacturing the above-floor plumbing units after handling several projects). This horizontal piping system became standard in construction after the Kasumigaseki Building (Uchida-sho committee 2002).

3.2.4 *Linear Ceiling System*

Work on the floors and walls tends to occur downward and sideways, but the ceiling requires upward work, which takes comparatively more labor. In addition, the attic is an area where various piping, wiring, and construction features, such as lighting, air conditioning, and sprinkler systems, come together. In the Kasumigaseki Building, a significant amount of streamlining was performed on the ceiling, as well.

The ceiling of the Kasumigaseki Building is a line ceiling. In conventional ceilings, lighting, air conditioning, sprinklers, speakers among other items can be placed anywhere; but, once the ceiling board is attached, it becomes necessary to drill holes and connect wires for the final touches. In contrast, in the Kasumigaseki Building, these facilities are placed in a line-shaped frame. Furthermore, by installing the equipment first, the conventional process of attaching boards to the ceiling and then installing the equipment is reversed. This greatly reduces the complexity of the process. Since the equipment is installed first, the rest of the line can be finished by applying a board to the ceiling. By putting the equipment ahead of the line, the start of power reception can also be accelerated, thereby reducing the need for temporary lighting. In today's office buildings, it is common to have a ceiling with a lattice-shaped frame that allows the installation of equipment in lattice-by-lattice units, but the line ceiling of the Kasumigaseki Building is based on the same concept. In addition, whereas in the past the ceiling would be finished on top of a plasterboard or other ceiling substrate, the Kasumigaseki Building is unique in that Mineraton – a sound-absorbing ceiling board manufactured by Nitto Boshoku Corporation – is applied directly to the H-beams.

3.2.5 *Deck plate*

In the same way as for the steel columns and beams, there are innovations to reduce weight and construction time for the floors. In the Kasumigaseki Building, U-shaped deck plates were developed for the floor. Until then, construction of a concrete floor required formwork, reinforcement, and casting. With so many trades working on site, it naturally was time-consuming. In addition, the formwork could not be removed until the concrete had reached a certain level of strength. The slab and beam formwork was supported from below by supporters, so that almost no work could be started on the floor below until the formwork had been demolded.

The deck plate is a zigzag folded steel plate. The standard dimensions of deck plates for the Kasumigaseki Building are 3,140 × 690 × 1.2 mm. While plate weighs 34 kg and can be carried by two people. Even a thin and light plate can be passed between the beams, and if concrete is poured on top of the plate, the rigidity of the deck plate itself will support the concrete so there is no need to support it with supporters below until the concrete hardens. Therefore, work can begin immediately on the floor below. In addition, it is not necessary to remove the deck plate. If the formwork is to be removed, it has to be brought back to the ground eventually, and in a high-rise building, the retrieval of this formwork is a major inconvenience. The effect of the deck plate development is also significant in this respect.

The reinforcement is placed on the deck plate and concrete is poured. The reinforcement was placed in the grooves of the deck plate one by one. The feature of the U-shaped deck plate developed for the Kasumigaseki Building is that the reinforcement is placed in the grooves in one direction. The installation is easy because the reinforcing steel bars are only placed in the grooves with spacers. In addition, the rebar is covered by the concrete in the groove with a certain thickness, eliminating the need for fireproofing. Wire mesh reinforcing bars were placed in the top.

The reinforced concrete and the steel beam need to be structurally integrated. For this purpose, large-diameter gibel stud welding was devised for the Kasumigaseki Building. A large bolt-like stud is welded to the steel frame and intertwined with the reinforced concrete on the deck plate to make it one piece. At the time, small-diameter bolt stud welding had been used in the manufacture of automobiles. However, in the Kasumigaseki Building, large-diameter stud welding was developing which made welding work possible even in rain and wind.

3.2.6 *Fire proofing*

A new dry method was developed for fireproofing steel frames. At that time, fireproofing of steel frames was done by pouring concrete or spraying asbestos material around the frame. However, once the concrete was cast, it was not consistent with the design of the flexible structure, and although spraying of asbestos and other materials had been used in Japan and abroad, it took time to control the thickness of the material. Therefore, a new method was developed for the Kasumigaseki Building in which fire-proofing material was prefabricated as a molded plate which was then attached on site using adhesive. This method shortened the construction period and reduced the cost by 20% compared to spraying asbestos. In the method of attaching the beams, large beams were attached to the inside of the flange, then small boards were attached to the sides of the flange, and small beams were attached to the sides of the flange to wrap the whole building. The pillars are also covered with the plates to wrap the whole structure. Special scaffolding was also used to affix the pillars and beams around the perimeter.

4 DISCUSSION

The construction methods used and developed in the Kasumigaseki Building project have been reviewed above. In addition, there were several characteristic construction methods in underground and curtainwall construction, among others. The Kasumigaseki Building was thoroughly designed to be lightweight and was prefabricated in order to achieve large amounts of work at high altitudes more quickly. Various new technologies, such as deck plates and piping systems, were developed and introduced with the cooperation of manufacturers. Many of these construction methods, including self-climbing tower cranes or deck plates, are now commonly used in slightly different forms in the construction of other high-rise buildings since 1968. The flexible structure is perhaps the best-known characteristic of the Kasumigaseki Building. In addition, a new process management method, PERT, the use of an electronic computer SERAC, and a method of lifting large amounts of materials and personnel were introduced to achieve continuous repetitive construction.

Figure 12. Deck plate.

Since the completion of the Kasumigaseki Building, the speed of construction and the capacity of machines have increased. Today, tower cranes can lift a 60-ton piece at a rate of only a few days for one standard floor frame. However, the most important point is that the construction of the Kasumigaseki Building was accomplished without any major problems – on schedule and without funerals. This is evidence that a series of technologies for constructing skyscrapers have been developed and proven to be effective. Specifically, the steel fabricators were equipped with steel frame processing machines, the engineers were able to obtain data on the building experience and construction steps, and the heavy lifting equipment was produced and operated in Japan. Lighter and shorter construction methods were also used, such as piping and ceiling materials.

It is also noteworthy that much of the data on the design and construction of the Kasumigaseki Building was made public by the participating entities. In terms of construction methods, numerous books and articles share information on various parts and processes, including the multiple proposals considered, their comparison tables, and labor steps (Figure 12).

5 CONCLUSION

This paper has expounded on the new construction methods applied to the Kasumigaseki Building and the impacts of these developments, particularly with regard to shortening construction time. First, the general contractors managed the construction process by the PERT method and using a mainframe computer. Second, to decrease the lifting or connecting by bolts, the steel posts and beams were divided into special units. The general contractor also developed a new floor system and tower cranes. In addition to the steel frames, several prefabrication and dry construction technologies were used, particularly in fireproofing materials, electricals, and piping. Some of these construction technologies had been used in other construction projects in Japan, and machinery capacity and construction details have since been changed. However, the true importance of the Kasumigaseki Building lies in the fact that these new technologies have been highly integrated into a single construction project.

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The skyscrapers of Milan: From experiments to recent constructive challenges

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ABSTRACT: After the pioneering experiments of Marcello Piacentini in Brescia and Genoa in the 1930s, the construction of the Rasini and SNIA Viscosa Towers shifted the Italian debate on tall buildings to Milan. This city subsequently became the focal point for the further development of this typology. The numerous tall buildings that were erected after World War Two brought about a profound urban, architectural and technological transformation of the city. Due to their great vertical and horizontal loads, increasingly complex supporting structures had to be developed for these skyscrapers, and intense collaboration between architects and engineers became necessary. Although the reinforced concrete frame was preferred, there were attempts to exploit the possibilities of the steel frame. This study, drawing upon information in historical and contemporary architectural and engineering periodicals, analyzes the proliferation of the skyscraper in Milan to increase our understanding of the intrinsic link between technological and stylistic renewal.

1 INTRODUCTION

As in Chicago, the erection of high-rise structures in Italy greatly expanded knowledge about sophisticated methods of construction on a national level (De Magistris 2004). Skyscrapers, generally opposed in the latter country for cultural, bureaucratic and environmental reasons, were built almost exclusively in the big cities of the North (Brescia, Milan, Turin, Genoa), while the examples in the South were rarer and more isolated (Naples, Palermo) (Colaianni 2002; Studio BBPR 1959). After the pioneering experiences of Marcello Piacentini in Brescia (Ina Tower 1932) and Genoa (Piacentini Tower 1935) (Talenti & Teodosio 2020b), the construction of the Rasini and SNIA Viscosa Towers shifted the Italian debate about tall buildings to Milan where it remains until today. Subsequently, numerous ‘towers’, as tall buildings in Italy were generally called, were inserted into the Milanese urban fabric, altering its structure as well as the proportions and the connections between the individual sections of the city (Talenti & Teodosio 2020a). As critical analysis of the specialized periodicals of the time, in addition to the extant project drawings, have shown, these skyscrapers renewed the city skyline, exemplifying the evolution of the relationship between form and structure (AA.VV. 2013). Furthermore, they were an extraordinary opportunity for experimentation from a formal point of view due to their usage of anti-rhetorical architectural languages that turned their backs on the past and opted for technical innovations in structural and plant systems (Alfonsi 1986).

The first examples, characterized by elementary volumes, were the direct expression of functional and structural needs, following the teachings of Viollet-le-Duc and Louis H. Sullivan (De Magistris 2004). After the Second World War, technical, architectural and aesthetic innovations in addition to the need for urban renewal forced architects to abandon schematic models in favor of increasingly complex and visually arresting solutions: thus the Park Tower (1953–56) by Vico Magistretti; the Galfa Tower (1956–59) by Melchiorre Bega; the Velasca Tower (1950–58) by BBPR architects (Banfi, Belgiojoso, Peressutti, Rogers); and the Pirelli Skyscraper (1953–60) by Giò Ponti and Pier Luigi Nervi have become icons of the Milan “skyline” and embodiments of the dialectic between structure and form, self-referentiality and formal expression.

Research about technological issues has always been pursued with great vigor in Milan despite the constraints imposed by the totalitarian policies of the Fascists and the cultural and economic factors that conditioned the choice of methods, structural systems and materials. For example, while the use of steel was discouraged, that of reinforced concrete – because it was cheaper, more easily available and already widely tested – was promoted (Livi 1999; Marzo Magno & Iori 2011). After World War II, although reinforced concrete continued to be widely employed, as evidenced by the articles published in professional periodicals of the time – from *Casabella* to *Domus*, from *Edilizia Moderna* to *L’Architettura. Cronache e Storia* – the structural experiments found in Milanese skyscrapers focused almost exclusively on the use of steel or of mixed solutions.

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2 STEEL FRAME VERSUS REINFORCED CONCRETE STRUCTURES

The steel frame was quite rare in Italy, especially in residential buildings. In Lombardy, the first 20th century 'towers' employed reinforced concrete structures for practical and economic reasons. The Rasini Tower by Giò Ponti and Emilio Lancia, for example, featured a reinforced concrete frame placed on a reverse beam structure that was designed by the engineer Gaetano Angilella (Coppa & Tenconi 2015, 276; Goldstein Bolocan 1935). Nevertheless, in a detailed article published in 1935 about the project and its site in Milan, the engineer Goldstein Bolocan emphasized that, despite the advantages of the monolithic concrete structure and the considerable savings in money, the choice of reinforced concrete had been carried out following an "intense factual campaign in favor of the steel frame" (Goldstein Bolocan 1935, 148). The article, published in *Industria italiana del cemento*, defended reinforced concrete because it was "logical", "rational", "cheap" and "national" (Goldstein Bolocan 1935, 158), suggesting a heated debate had taken place about construction techniques and the supporting structural elements. Other sources, however, seem to attest that the steel frame option was struggling to gain acceptance by Italian professionals, who somehow seemed to prefer to remain on the sidelines of the discussion. They often stated, in a rather simplistic way, that the well-known American method of skyscraper construction could not "be applied to our structures which are so different from the metal ones of overseas builders" (Cevini 2001, 75; Traverso 1941).

The Littoria Tower in the Sempione Park, an observation 'tower' featuring a diaphanous steel construction, was commissioned by Mussolini and designed in 1932 by Giò Ponti. It was a notable exception in Italy at this time (Irace 2009). Designed to celebrate the magnificence and the modernity of the Fascist Regime, it displayed tubular elements produced by the Milanese Company Dalmine and connected using the arc welding technique, which had recently been introduced into Italy for buildings (D'Orazio 2008).

Prior to the invasion of Ethiopia (1935) and the subsequent international sanctions imposed on Italy, which forced the government to instigate economic policies based on self-sufficiency and limit the consumption of steel for the war effort, some architectural designs presented to the *V Triennale di Milano* (1933) explored the use of steel construction for residential buildings (D'Orazio 2008).

One particularly interesting scheme depicted a tall, slender house with a steel structure, articulated as a white, glazed building with balconies (Daneri 1933).

Conceived by a group of Ligurian architects, including Luigi Vietti and Carlo Daneri, it was created as a model of a "modern high-rise collective dwelling" (D'Orazio 2008, 53). Nevertheless, despite their well-informed knowledge of steel construction systems, Italian professionals were loath to abandon reinforced concrete. Other examples found at the 1933 *Triennale* – including the design of a small steel house by Pagano, Camus, Palanti and Mazzoleni, where the supporting structure was left exposed precisely to reveal the advantages of this material – did not trigger a debate on the application of steel frame construction.

Figure 1. Model of the steel skyscraper by Daneri (Daneri, 1935, 9).

Daneri remained an isolated case, however, as he continued to design skyscrapers with steel frames. For the tower commissioned by the Badoni Anonymous Company of Lecco, in 1935, the architect proposed a metal skeleton that would support both the slabs and the internal and perimeter walls, freeing the latter elements from all static functions and leaving them the task of enclosing the interior space (Daneri 1935) (Figure 1). According to its creator, the steel structure would have allowed the building not only to rise to a lofty height with a maximum guarantee of safety but also allow for the reduction of the dimension of the load-bearing elements on the lower floors, thus enabling a freer organization of the plan. This method also returned economic benefits (Daneri 1935; D'Orazio 2008).

The experiments that were carried out in those same years by the architect-engineer Guido Fiorini were also significant. In collaboration with a Company from Piedmont (Società Nazionale Officine di Savigliano), specialized in railway, mechanical and electrical constructions, he developed a scheme for a tall building supported by a tensile structure in 1930 (Pisanu & Sanjust 2017). Fiorini's experiments, appreciated by Le Corbusier with whom he began a fruitful correspondence, were based on the use of steel structures designed to be built in series, with a rigid central block from which, by means of metal tie-rods, the cantilevered floors were suspended (Talamona 2012).

The system could be adapted for use in a residential building. Writing in 1934, Fiorini emphasized that the advantages included: the speed of construction, the absence of mistakes on site, and the safety of the structural calculations (Fiorini 1934). The involvement of the Savigliano Company, as well as of the Badoni Anonymous Company, testified to the efforts in modernizing the Italian construction system, particularly through research and innovation. But, despite the attempts made by the manufacturing industries on the one hand and the promotion, experimentation and enthusiasm of the protagonists of the 1933 *Triennale* on the other, the autarchic policies imposed by the Fascist Regime discouraged the use of steel. In 1935, a circular issued by the National Secretary of the Architects' Union, advised "to proceed to the realization of buildings employing exclusively our own material", and called for the elimination of "all the uses of all those materials which, especially in recent years, followed the example of foreign constructions" (D'Orazio, 2008, 63).

3 A BRIEF HISTORY OF THE STRUCTURES OF SKYSCRAPERS IN MILAN

Although the utilisation of steel skeletons was unusual in Italy, there were some rare exceptions. Of note is the Tower for the Reale Mutua Assicurazioni Society built in Turin in 1934 by Armando Melis and Giovanni Bernocco. It was the first multi-storey building in Italy with an electro-welded metal structure (D'Orazio 2008). Yet the introduction in 1938 of a section entitled "Metal constructions" in the periodical *Casabella* did not lead to further projects. Likewise, the rare Milanese high-rise projects of the 1930s, such as Alessandro Rimini's SNIA Viscosa Tower or Mario Bacciocchi's Tower for offices and dwellings (1936–39) did not adopt steel frames. Indeed, site conditions often favored the possibilities available with reinforced concrete. Due to the irregularity of the alluvial soil on which the SNIA Viscosa Tower stood, the engineer Guido Mettler distributed the load of the foundations on a 1 meter high plate that was comparable to a "very rigid inverted slab" (Disertori et al. 2002, 81; Goldstein Bolocan 1935) (Figure 2). For others, concrete had distinct aesthetic advantages. Goldstein Bolocan noted the extreme plasticity and versatility of this material by stating that "the framework in RC of San Babila Tower is a rather infrequent example, therefore even more deserving of publication, of the characteristic constructive adaptability of the reinforced concrete to the material needs, and sometimes to the whims, of the architectural project" (Goldstein Bolocan 1936, 331). Despite the progress of structural engineering, the first real skyscrapers built after World War Two used reinforced concrete structures: the Swiss Center (1947–52) by Armin Meili and Giovanni Romani, containing 20 stories and rising to a height of 80 meters; the Breda Tower (1950–55) by Luigi Mattioni, known as the 'skyscraper of Milan' par-excellence and celebrated as the tallest reinforced concrete structure in the world (Alfonsi & Zucconi 1985); the Park Tower by Vico Magistretti, etcetera.

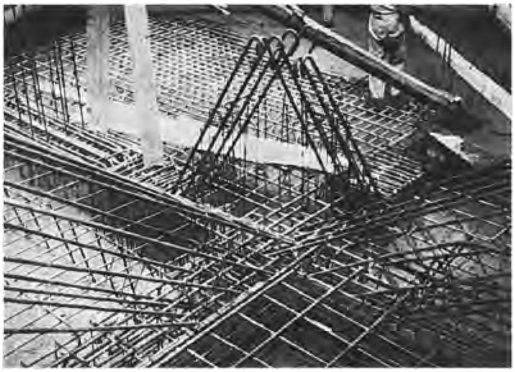

Figure 2. SNIA Viscosa Tower. Construction of the foundation plate (*L'industria italiana del cemento*, 1936, 12, 329).

Nevertheless, the 1950s witnessed some timid – often abortive – attempts to apply structural steel in Milanese skyscrapers. The first proposal for the Torre Velasca by BBPR envisaged a steel structure, whose design had been developed by a construction company based in New York in 1952 (Editorial 1959). Due to the high costs and the accompanying curtain wall reminiscent of International Style aesthetics, the idea was abandoned. Then, the engineer Arturo Danusso designed a structure with a central bracing core, which included stairwells and elevators, and a perimeter frame with rigid knots composed of sixteen trilobate jutting pillars that run the entire height of the facades and are emphasized only by their real material consistency (Samonà 1959). The crowning of the building, consisting of 7 floors and technical volumes protruding from the main body, was supported by a series of compressed inclined struts and horizontal elements that worked as tie rods (Figure 3). The solution proved to be particularly innovative, so much so that it was also exported overseas and used for high-rise buildings in Chicago (Sumini 2015).

The same issues arose in the design and construction of the Galfa Tower (1956–59), designed by the architect Melchiorre Bega (Greco & Mornati 2012). Rising to a height of 103 meters, its pure form and references to international models were made possible by its simple structural system, which nonetheless contained technological and constructive innovations (Vaccaro 1956). The first scheme proposed a steel frame, but the young structural engineer Luigi Antonietti rejected it because "we weren't as advanced in the use of steel as we were with the use of reinforced concrete, it was poorly studied, there were few examples. At that time, steel was forbidden, there wasn't any, or no one knew how to work it. Consequently, there were few companies able to meet market demand" (Magni 2014, 107).

Although Bega had long been fascinated with steel construction usage, he accepted a reinforced concrete construction: "I have always dreamed of building in

Figure 3. Velasca Tower. *L'Architettura. Cronache e Storia*, 1959, 40, 673).

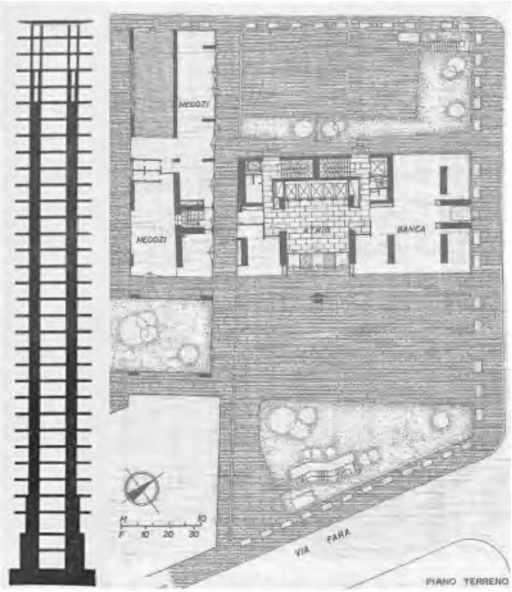

Figure 4. Galfa Tower. Longitudinal section and ground floor plan. (*L'Architettura. Cronache e Storia*, 1959, 6, 370, 375).

steel because for me steel has an emotional strength. Steel is one of the most suitable materials not only to solve what is the greatest concern of contemporary engineering, the concern for increasingly solid and ever more daring load-bearing structures, but it has its own natural and immediate elegance that fascinate …" (Coppa 2015, 331; Giolli 1937). According to Bega, steel was the bearer of "speed of realization", of "greater space", but also of "cleanliness, simplicity and clarity" (Giolli 1937, 7). Nevertheless, he explored his fascination for steel in the articulation of the elegant and unusual American-style curtain wall of his Milanese skyscraper, which displayed an array of modern technologies, including prefabrication, innovative manufacturing solutions and the sophisticated detailing of the supporting frame.

Signed by the engineer Danusso, the Galfa tower consisted of six load-bearing piers that were placed perpendicular to the facades but arranged asymmetrically and irregularly (Figure 4). It was a particularly innovative static system, in which the weights were loaded onto the vertical partitions, differently oriented, thus solving the need for bracing in the tall building (Bega 1959). In addition to the stiffness obtained and the uninterrupted glass front, this design allowed for a more rational use of interior space than a structure comprised of beams and reinforced concrete pillars, whose sections, in the basement, would have been rather bulky (Coppa 2015). However, if in his other Milanese skyscrapers – including the two unrealized projects for a high-rise in the form of a spire and another planned for Loreto Square – Bega had opted for reinforced concrete structures, a few years later he decided to test (together with architects Piero Gambacciani, and Attilio Viziano) the steel frame in the SIP Tower in Genoa (1964–68), inaugurating the first Italian tall building with this type of supporting structure and prefabricated elements (Pedio 1970). At the time, there were a number of arguments in favor of the Ligurian solution: simplicity, immediacy, quick assembly that was independent of climatic conditions and which required few pieces of equipment, and finally cost efficiency (GenovaMetropoli 2014).

In Milan, meanwhile, one of the most significant and original Italian skyscrapers of the post war years, the famous Pirelli Tower (1953–1960), designed by the team coordinated by the architect Giò Ponti (Edilizia Moderna 1960). The elegant form is articulated as a tapered slab and features an extremely narrow plan (the width is 18.5 m, the height 70.4 m) (Ponti 1956). Danusso, with the engineer Pier Luigi Nervi, abandoned the traditional frame, developing an innovative structure with rigid triangular partitions at the ends of the building, hollow pillars and 4 large central pillars with a butterfly section, tapered upwards and able to withstand even horizontal stresses (Figure 5). According to Ponti, the so-called 'Pirellone' achieved "that typical structural determination of the building which in the end is identified with its own architecture" (Ponti 1956, 2). Experimentation, practical knowledge, a perfect means of execution combined with industrial production in the service of architecture, not to mention the poetry of architectural creativity,

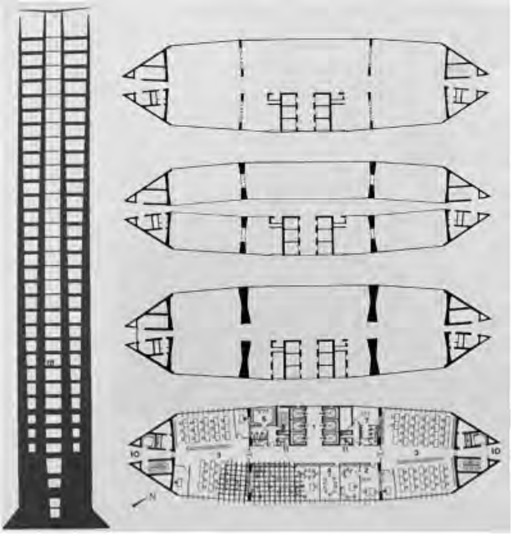

Figure 5. Pirelli Tower. Longitudinal section and plans. (left: *Domus*,1956, 316, 5; right: *Comunità*, 1959, 74, 87).

rendered this ‘tower” one of the icons of the modernity of the Milanese Reconstruction.

4 FROM THE SIXTIES TO THE NEW ‘VERTICAL FEVER’

Following the immediate post-war period, the 1960s saw the construction of various high-rises in Milan, often for residential purposes. These towers were frequently located outside the historic center, considered as an answer to the dire need for housing. For example, the BBPR architects took up this challenge, and designed eight skyscrapers for the new district of Gratosoglio (1963–71) on the southern outskirts of the city (Piva 1982). Here, the rigid prefabrication system that the architects were required to use limited their ability for invention, and the resulting floor plans were extremely schematic. The towers of the Istituto Case Popolari in the Gallaratese district (1963–71), designed by Magistretti, are a significant example of prefabricated, self-supporting reinforced concrete panel construction, based on a British patent which involved the prior assembly of the panels and diverse installations in the factory (Archivio Vico Magistretti n.d.).

In the historical center of the city, however, interest in skyscrapers slowly waned. Among the few designers to try their hand at this type of building, we can include the elderly Milanese architect Giovanni Muzio together with his son Lorenzo, creators of the Turati Tower (1966–1969) (Verger 1994). In contrast to the Velasca and Galfa Towers, the initial project called for a reinforced concrete structure set on load-bearing walls. But to reduce the construction time, a steel skeleton was selected. The steel framework of the 19-storey tower rests on a reinforced concrete structure that includes two underground floors, remaining partially visible on the south and north facades. In this case, however, the tower’s prefabricated reinforced concrete curtain panels were employed to absorb the elastic deformations of the structure (Bernasconi 1969). The Turati Tower concludes the vertical experimentation in Milan because the 1970s saw the growing rejection of such ‘towers’. Demands changed, especially in residential areas, but also the symbolic meaning of the tall building, which no longer represented an ideal of modernity or served as a status symbol of the economic miracle of the Milanese bourgeoisie.

Figure 6. Unicredit Tower (author’s photo, 2019).

Since the 2000s there has been a new ‘vertical fever’ in the capital of Lombardy, especially in some neighborhoods that have recently undergone renewal processes, such as the Porta Nuova district or City Life (the former Trade Fair district), where new building sites have become available in the urban fabric (Molinari 2015). Concrete continues to dominate the construction of all structural elements, and not just for the cores and shear-walls. In recent decades, moreover, the growing resistance of cementitious conglomerates – obtained through production techniques and implementation procedures that are increasingly more sophisticated, without affecting costs – and the progress of pumping techniques that can bring concrete up to great heights, explains the infrequent use of steel in the tall buildings of Milan.

The Unicredit Tower (2014) by the Argentine architect Cesar Pelli is the tallest skyscraper not only in Milan but also in Italy. It is supported by a rather ordinary reinforced concrete frame. The most challenging part of the construction was the erection of the pierced steel spire (echoing the gothic spire of Milan’s cathedral and showing an ever-present link with the tradition), placed at the top in an eccentric position with respect to the body of the building (Molinari 2015). The expressive element, whose design required considerable structural analysis, displays a spiral structure, covered with colored LEDs that were installed using a helicopter (Videomaker Insubria 2011). Furthermore, thanks to decisions aimed at saving energy and reducing CO2 emissions, the building was the first Italian pilot project to have obtained the US Green Building Council’s Leed Gold certification (Figure 6).

Figure 7. CityLife District (photo by Mariateresa Monteverdi 2021).

Currently, Milan is also home to the tallest building in Italy with a steel frame: The Diamond Tower (2012) (Badia & Valente 2012). The American architects Kohn Pedersen Fox Associates (KPF) in collaboration with the Arup structural engineering firm and the Pichler Company (responsible for the steel structure and the curtain walls) created the futuristic design. It rises to a height of 147 meters and has a central, reinforced concrete core and external steel skeleton (Manganelli 2012). Lighter than a conventional reinforced concrete structure, the tower rests on a shallow slab, as deeper foundations on piles were not required. Due to its higher strength, the S460 steel that was employed here allows for slender and highly efficient columns. This material is economical and provides large open spaces that are suitable for offices. Moreover, in this case, the steel perfectly supports the building's complex geometry; the construction time, at one year, was fairly short. This skyscraper represents an important milestone for the Italian steel industry and has contributed to the recognition of the advantages of this material: prefabrication, mechanical properties, aesthetic potential, recyclability, speed of assembly and sustainability.

Three final skyscrapers, recently built in the new CityLife district, are significant examples of mixed reinforced concrete and steel frame constructions (Serrazanetti 2018) (Figure 7). The Allianz Tower by Arata Isozaki (2012) is one of the tallest high-rise buildings in Italy (Isozaki & Maffei 2020). Whereas the form recalls Costantin Brancusi's endless column, its construction is based on an indefinitely repeatable, 6-storey module (Biagi 2015) (Figure 6). Developed by Arup Company, the structural solution included two pairs of external steel struts, like crutches, to guarantee stability, allowing the elimination of some supporting pillars inside the building (Coppa & Tenconi 2015). Two concrete cores, symmetrically placed on the short sides, contain the glass shafts for the elevators. These are a tribute to Milanese futurism, showing the idea of a 'building as a machine', with exposed gears that are in constant movement. At the 24th floor, two steel belt trusses connect the cores.

The Hadid Tower (2017) – designed using various visualization models and new software especially created for the calculation of the loads and torsion of the pillars (Zaha Hadid Architects undated; INGENIOvideo 2018) (Figure 6) – testifies to the ongoing research in innovative structural systems. The so-called 'twisted tower', with its rotation and form that tapers upwards, is a perfect example of the synthesis between an architectural idea and a structural solution (L'involucro 2016). The building, fanning out from a central concrete core, has different floorplans and arrangements of columns at each level. According to the designers, they selected a reinforced concrete skeleton for both economic reasons and because of the material's adaptability to architectural intentions and engineering requirements.

The PwC Tower by Daniel Libeskind completes the trio and, with its irregular shape and variable geometry, seems to challenge the laws of gravity. It has a reinforced concrete frame and its roof is topped by an arced asymmetrical plane, rendered in metal and glass. This sort of crowning, like a Renaissance dome, is a signature element of the project and hides the technical equipment that are typically found on the top of tall buildings. These skyscrapers were a product of the interdisciplinary skills of their design teams; they also benefitted from advances in construction technology, improvements to energy performance levels, and a more conscious use of environmental resources and choice of materials. In a similar vein, it should be noted that other recent 'towers' in Milan have now embraced traditional and natural materials, such as the wood for the structural cage (X-LAM technology) in the four buildings called "Cenni di Cambiamento" (2013) or the vegetation on the famous "Bosco Verticale" (2014) by Stefano Boeri.

5 CONCLUSIONS

This study investigated historical and contemporary sources to analyze the most significant Milanese skyscrapers of the 20th and 21st centuries. The results show that the structural and constructive aspects of this architectural typology have fueled a fruitful debate and led to a variety of solutions. Innovation focused on the optimization of the various parts of the reinforced concrete framework (foundations, vertical and horizontal structures, bracing) as well as the gradual introduction of the steel skeleton. On the other hand, there was almost no innovation in the production process; in fact, in-situ concrete construction continued to be employed and, with the exception of some housing projects in the 1970s, the use of prefabricated elements was rare.

For economic and logistic reasons, concrete was seen as the most suitable solution for the structural frames of Milanese skyscrapers. Therefore, the constructive and technological innovations have concentrated on this material, giving rise to the contributions of notable Italian structural engineers, such as Danusso or Nervi, who devised technological solutions that still remain cutting-edge today. The central core bracing with perimeter pillars of the Velasca Tower, for example, is still considered to be an optimal structural solution for very tall buildings, such as the Burj Khalifa in Dubai (Parker & Wood 2013). Furthermore, in the 1950s, to verify the structural calculations of some skyscrapers, a new methodology, based on laboratory tests and model experiments, was developed (Neri 2014) (Figure 8). As Gabriele Neri pointed out, in reference to a speech given by Danusso at the Milan Polytechnic, "the model was the only means by which to bypass the limits of the theory of construction science and to verify, instead, one's own 'static intuition', an indispensable and preferential skill in the tortuous process of defining a structural form" (Neri 2015, 315). Indeed, the value of these buildings, from Velasca to Pirelli, lies in the integration of innovative technical knowledge and sophisticated design, a combination that had previously been separate from one another (Colaianni 2002). This synthesis inspired the search for innovative solutions to integrate structural, formal and functional concerns.

Today, in Italy, mixed structural solutions for high-rise buildings are preferred and the use of steel frames is significantly lower than in other European locations. Furthermore, attention to construction strategies now engages growing interest in sustainability which presents new challenges. Like the 'towers' of Milan, this new direction will require the synergy of numerous and highly specialized professionals in the building industries to produce seminal works of architecture in the future.

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Thematic session: Form with no formwork (vault construction with reduced formwork)

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History of Construction Cultures – Mascarenhas-Mateus & Paula Pires (eds)

Brick vaulting without centering in the Mediterranean from Antiquity to the Middle Ages

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ABSTRACT: Fired-brick vaulting without centering is documented in several examples and over quite a large territory. In antiquity and the Middle Ages, we find three different solutions in the Mediterranean Region: dry-brick vaults, lime-mortared brick vaults and gypsum-mortared brick vaults. The article offers a concise overview of the evidence and offers a possible understanding of the historical context which fostered innovation in brick vaulting.

1 INTRODUCTION

Fired bricks offered innumerable advantages for construction, providing a valid alterative to stone construction since their versatility and size made the assembly of building material to form a structure easier (Vitti 2019). Moreover, bricks could be easily modelled to match the requirements for customized elements necessary to meet formal and structural demands, making fired bricks an ideal material for vaulting. Another advantage of brick was that by reducing the dimensions and weight of the single unit forming the vault, it was possible to minimize, if not avoid altogether, provisional supports during construction.

The aim of this essay is to discuss three different solutions: dry-brick vaults, lime-mortared brick vaults and gypsum-mortared brick vaults.

2 A LATE BRONZE AGE BRICK VAULT IN CYPRUS

The earliest fired-brick vault documented so far in the Mediterranean is a tomb at Enkomi-Alasia, on the east coast of Cyprus. The “tholos” tomb (T1336), discovered in 1963, was interpreted by the archaeologists as a cantilever structure, a technique employed in Mycenean construction. However, in-depth analysis of the masonry reveals a different and exceptionally avant-garde vaulting technique based on a radial disposition of bricks.

Enkomi-Alasia was a well-organized and prosperous Bronze Age settlement. The dead were occasionally buried within the city walls. Tomb 1336 is one of the tombs that was partially preserved because it was built over at a later date (Figure 1). This construction has an irregular beam form and measures 320 × 250 cm. The burial goods found in the tomb date its construction to ca.1400 BCE and document a period of use of ca.150 years (Johnstone 1971: 113–115).

Extant remains consist of roughly radially-placed bricks, abutting on a stone wall support. The inclined disposition of the bricks is clearly a departure from cantilever construction, which is characterized by stones layered horizontally. This arrangement transmits the load from one brick to the other according to the structural principle of the arch. The bricks were custom-made in a trapezoidal form, which measured 31–40 × 32 × 11–12 cm and was specially designed for the purpose (i.e. not reused). Bricks were placed side by side with their short sides touching each other to form brick rings.

That builders were concerned about the stability of such brick rings is evident, since above the haunches of the vault the bricks were alternated with a single ring of seashell conglomerate headers inserted between the brick courses (Figure 2). These stone headers extended beyond the brick shell, so as to be stabilized by the stones above them (Figure 1-D). Based on the bricks that were found collapsed into the tomb and the disposition of the ones that still remain in the vault, Johnstone argued that the vault could not have had a brick crown, suggesting that a stone slab may have formed the uppermost part of the construction. A similar solution was found in the tholos tombs on the site, such as T21 and T1432 (Pelon 1973: 249–253), where a stone slab was placed on top of the beehive-shaped tomb.

Since the other tombs were built with the typical technique of cantilevered stone construction and differ from the fired-brick vault, this author believes that T1336 had a crown entirely built with bricks, and that the upper part of the tomb was lost during the construction of a house above it dating to the Mycenaean III C-1 period (ca. first half 12th century BCE).

The remarkable thickness of the bricks (11–12 cm) corresponds to standards adopted for mud bricks, typically thicker than fired bricks. Each brick has one slightly concave side, so that the edges are thicker than the central part, possibly as a result of pressing the clay

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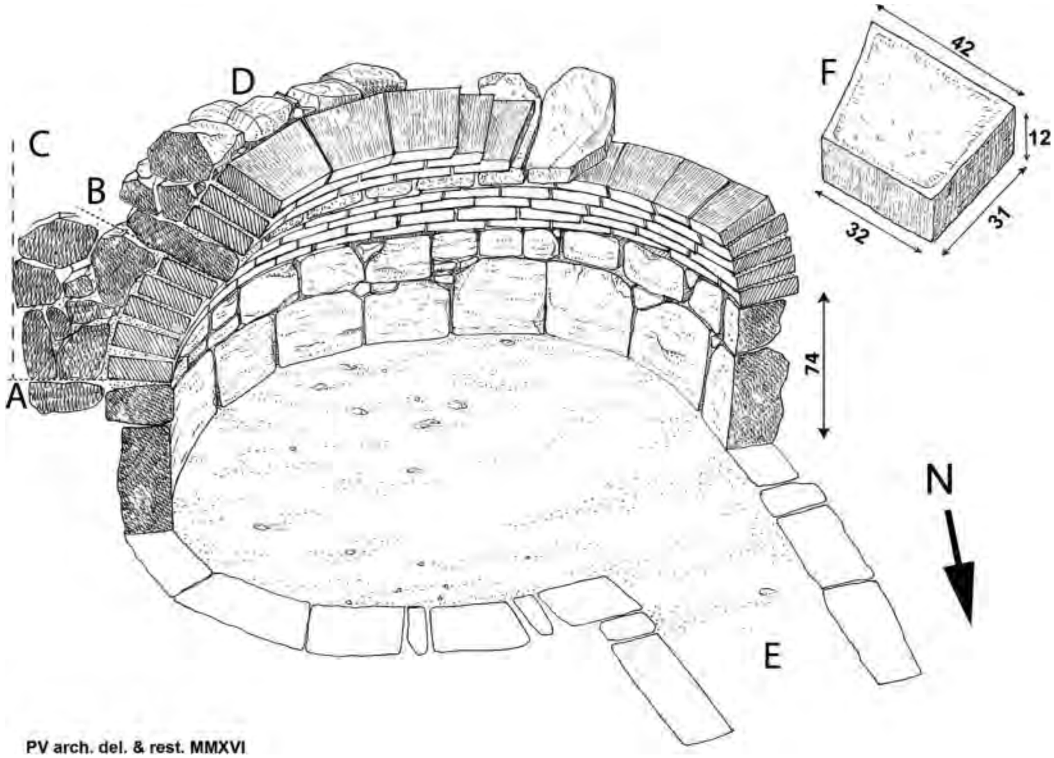

Figure 1. Diagram of the Late Bronze Age Tomb T1336 at Enkomi. A: impost of the vault; B: row of stones at the haunches; C: back-wall retaining the filling; D: filling above the brick shell stabilizing the stones at the haunches; F: fired brick.

Figure 2. Detail of the brick vault. A) row of limestones set at the height of the haunches. B) rubble stone filling.

well into the timber frame used to shape the bricks, a detail that can be seen in later archaic bricks in Lemnos (Correale & Vitti 2019) or Assyria (fired, stamped bricks from Nimrud). The bricks are pale brown in colour, with a black-clay core, a typical result of low levels of oxygen during firing, showing an imperfect technical capacity to control the production process.

The use of fired bricks and the technical solution adopted in the construction of the vault is remarkable in itself, and clearly indicates technology not documented elsewhere in Cyprus at that time. Firing clay was not, of course, a new development for Cyprus, where ceramic production is well documented. But its employment in construction was a novelty at a time when exclusively natural materials (stone, wood, mud bricks) were used, with no exceptions (Wright 1992).

Tomb T1336 thus provides unique evidence of skilled workmanship and use of fired bricks specially produced for the construction of the vault.

As the vault is formed from overlapping rings, it resembles Mycenaean tombs with ashlars laid in concentric rings. On the other hand, the use of fired bricks, unprecedented in the Mediterranean, points to the influence of the Near East, where this technique is well documented (Sauvage 1998). Despite the difficulty of proving such technological exchange in the tomb at Enkomi-Alasia, the evidence demonstrates the ingenuity of the builders of the period in adopting a vaulting technique which employed small building elements custom-made to meet structural needs, as well as facilitate the construction process, so as not to require any provisional support for the bricks during construction. In fact, using trapezoidal bricks placed side by side reduced the join between two contiguous elements, thus preventing bricks from sliding from their inclined position. The clayey soil provided minimal adherence during the construction of each ring, and, by giving a wedged shape to the joint, made it possible to increase the angle of each ring. Each ring, once formed, was in fact stable. This procedure resulted in each successive course slightly protruding beyond that of the one below, and not lining up smoothly (as happens when using a timber centering).

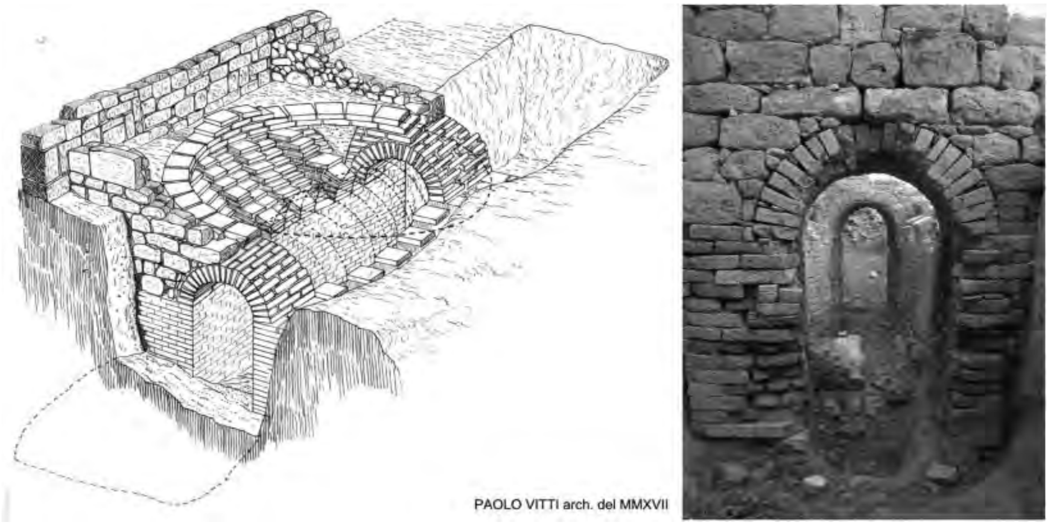

Figure 3. Diagram of the Great Furnace in Morgantina and view of the northern *praefurnium*.

3 EARLY BRICK VAULTING IN HELLENISTIC TIMES

The tomb of Enkomi-Alasia so far remains an isolated phenomenon, with no clear follow-up until the Hellenistic times, when fired-brick vaulting is documented again, as in the Great Furnace in Morgantina, Sicily, dated to a period following the Roman conquest of the city, i.e. after 211 BCE (Cuomo di Caprio 1992: 4) (Figure 3).

In Morgantina, no bonding agent was used and contact between bricks was improved by small terracotta chips. The arches giving access to the firing chamber and those supporting the floor of the furnace were made of voussoir bricks, custom-made wedge-shaped bricks which, as in Enkomi-Alasia, served to transfer the load from one brick to the other, avoiding the necessity of a binding agent that here would have been exposed to vitrification.

Evidence of highly-specialized technological expertise in the construction is furnished by some bricks tempered with chamotte grains. Chamotte is a finely ground ceramic material, generally obtained by firing particular types of clay at a high temperature, and contains a high percentage of silica and alumina. Chamotte considerably reduced shrinkage during the drying process, but also improved resistance in fired bricks, especially when exposed to thermal shocks such as in a furnace.

The Great Furnace is a good example of how the development of a building technique goes hand in hand with many parameters, including technological know-how, availability of materials, evident need for new solutions, experience in solving practical matters and the capacity to balance structural-resilience requirements with the simplification of the building process.

Although the Morgantina furnace employs arches built on centering, thus falling outside the scope of present article, it must be mentioned here because it illustrates that some four centuries passed before brick vaulting without centering was introduced as common practice in the Mediterranean. This change occurred in late 1st century CE, when new technical know-how was imported from the East.

4 LIME- AND GYPSUM-MORTARED BRICK VAULTS IN ANTIQUITY

Brick vaulting in the Roman times started with the spread of fired-brick construction (3rd century BCE). It employed predominantly lime mortar. Dry-brick vaults, such as those found at Norcia, central Italy (Anzani et al. 2019), are rarely documented. It is likely that Romans imported fired-brick construction from southern Italy (Bonetto et al. 2019). Solid-brick vaulting – i.e. vaults entirely built with bricks and not concrete vaults faced with bricks – is well documented in northern Italy and in Greece. In the Peloponnese in Greece, where the evidence is abundant, small- and medium-span vaults (2–5 m) date at least from the 1st century BCE. These early vaults were all built on centering, and created with mortared rubble set on the brick shell so as to replicate architectural models that in Rome and its environs were made entirely in concrete (Vitti 2016: 68–72). In order to reduce centering, the first sector of the vault (30°) was as often as not built without centering, while the remaining sector used a flying centering. Vault construction without centering appeared in Greece only with the introduction of the so-called pitched-brick vaulting from the East (Lancaster 2010).

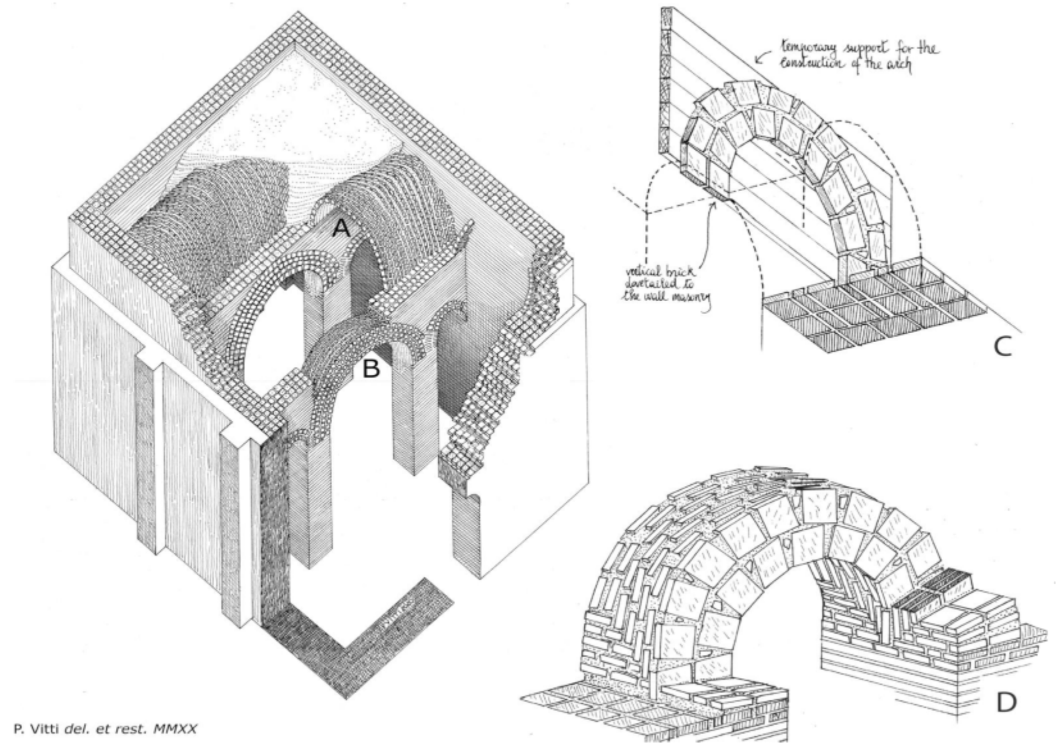

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Figure 4. Diagrams of the pillared Hall of the Palace of Assur. A) vertical-brick barrel vaults; B) vertical-brick arches; C) diagram showing hypothetical construction of the first layer of the arches; D) detail axonometry of the arches.

Pitched-brick vaulting had a long tradition in Egypt and Mesopotamia, dating back at least to the third millennium BCE (Benseval 1984, Lancaster 2015: 40–42). Here both "pitched" and "vertical" bricks were used. In the 1st-century CE Palace of Assur (in present-day Iraq) the "pillared hall" was built with fired-brick vaults and arches. Bricks were mortared with gypsum, which was abundant in the region. The hall was roofed with three barrel vaults side-by-side, each about 4 m wide, springing from walls supported by pilasters and arches (Figure 4). These vaults were built without centering, with pitched-brick arches laid one against the other, starting from the end wall, and becoming progressively more vertical towards the center (Figure 4-A). The arches opened in the supporting walls instead of being built with bricks placed radially (as one would expect), and were also built with vertical-brick vaulting. The central arch was 5 m wide and was flanked by two smaller arches (approx. 1.60 m span) (Figure 4-B). It is worth emphasizing that these arches featured vertical-brick vaulting without the first layer being laid against a wall. It can be supposed that a timber element was used to give temporary support while the first vertical arch was being laid (Figure 4-C).

The introduction of vertical-brick vaulting by Roman builders in Greece occurred at a moment of well-established (and frequently conflictual) contacts with the Middle East, and particularly with the Parths (Lancaster 2015: 64–66). The Roman vault differs from the Parthian pitched- and vertical-brick vault in that it employs lime mortar. By the end of the 1st and start of the 2nd century CE, lime-mortared vertical-brick vaulting was used frequently in the Peloponnese as an alternative to the traditional radial-brick arch, hence establishing a solid tradition of brick vaulting without centering. Thorough discussion of the many examples documented in the Peloponnese is not possible in detail here. Suffice to say that pitched- and vertical-brick vaulting was adopted in the construction of barrel vaults, cross vaults, sail vaults and niches (Figure 5) (Vitti 2016). This building tradition became common in Greece and Asia Minor, to the point of considerably influencing Byzantine architecture (Karydis 2011; Ward-Perkins 1994).

5 GYPSUM MORTAR AND TILE VAULTING. THE CONTRIBUTION OF THE ALMORAVID BUILDERS

Another significant revolution in the Mediterranean region occurred 1000 years later under the Almoravid dynasty when brick-vaulted construction with gypsum mortar was introduced. Following the foundation of Marrakech (1070 CE) by the Almoravid rulers, fired bricks started to be used in the western Islamic regions (Morocco and Al-Andalus), together with gypsum as a bonding material for brick vault construction

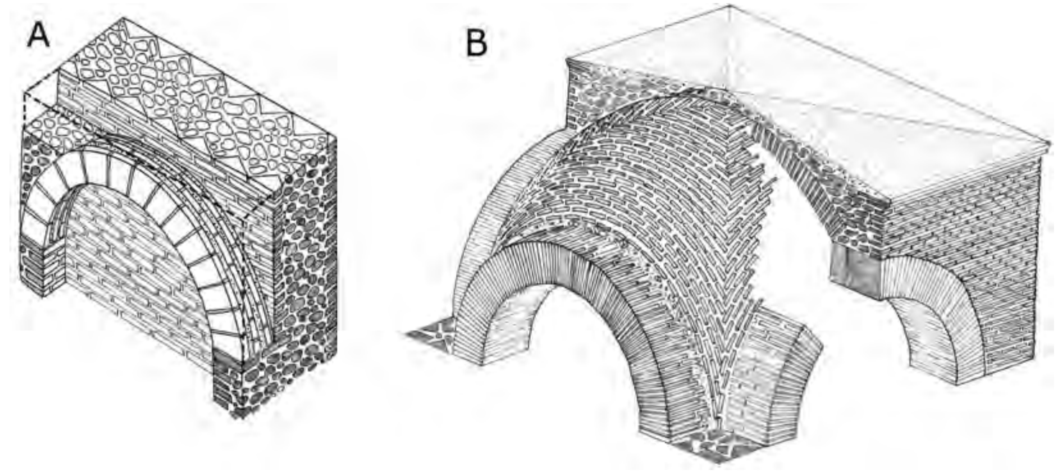

Figure 5. Lime-mortared vertical- and pitched-brick vaulting. A) diagram of a barrel vault; B) diagram of a sail vault.

(Vitti 2020, Vitti, in prep.). In fact, brick construction remained rare in medieval Spain (and Morocco) before the 12th century, and is documented again only after the expansion of the Almoravids in Al-Andalus (e.g. in the Giralda in Seville). The first tile vaults did not appear in the region until the end of the 12th century (Zaragozá 2012). Tile vaults differ from earlier brick vaults since they use gypsum mortar and bricks are laid flat, side by side, to form the surface of the vault. The Palace of Assur again provides crucial evidence when tracing how tiles vaults were introduced into the Mediterranean region.

As discussed, in the hall of the Palace at Assur vertical-brick vaulting was adopted for a freestanding structure (i.e. not laid against a wall). Brick arches in Assur were ca.144 cm thick and made of 18 layers of bricks 8 cm thick (slim arches), each layer a single brick thick (Lenzen 1933: 44). The progressive reduction of the number of slim arches occurred in later centuries and made it possible to form brick ribs, which, when made in accordance with the vertical-brick construction technique, in turn led to technical virtuosity in creating lightweight structures and the use of an interlaced design (Fuentes & Huerta 2010). In the congregational Jameh Mosque of Isfahan, dated between 1090 and 1150, ribs are 30 cm wide while the thickness is variable (greater at the haunches). The area between two brick ribs was filled with thin brick shells (Vitti, in prep., Galdieri 1983).

This technical know-how was imported by the Almoravids to Marrakech and is documented in the Qubba al-Barudiyyin, a building which served as a ceremonial fountain at the heart of the city. The exterior dome (4 m span) is a massive brick construction 50 cm thick made with radially-placed bricks (Figure 6). The interior lobed dome (2 m span) was built in a completely different, unique and unprecedented manner. Its structure is composed of brick ribs supported by timber beams, bracketing from an octagonal drum. The 4-cm-thick ribs are made of rectangular bricks placed on their thin side and resemble the brick ribs in Isfahan and other sites, with the difference that here they are formed of a single row of bricks. The wedges between the ribs were made of bricks laid flat, side by side, thus forming shells as thick as the bricks (4 cm). While lime mortar was employed for the brick masonry of the building and the exterior dome, the lightweight structure of the interior dome was built with gypsum mortar. During construction, gypsum was used to fill rapidly the gaps formed by the triangular joints between one radiating brick and another, making it possible to form the vault without centering. Then a layer of gypsum was employed to cover and reinforce the ribs and the wedges in between (Vitti 2020).

6 CONCLUSIONS

The examples that have been discussed show three different solutions for brick vaulting without centering which were introduced in the Mediterranean at a time when foreign expertise encountered a well-established local building and architectural tradition.

Dry-brick vaulting remained quite an exceptional and isolated architectural form since depended on the wedge shape of the bricks, as in the case of a dry-stone arch/vault. It was typically employed in furnaces and limited-span structures.

Once introduced into the West from the East, lime-mortared vertical-brick vaulting became quite popular. The mastery of the Romans was to adapt the vaulting technique to their architectural models. This solution evolved in Byzantine architecture in small- and medium-sized vaults with new technical solutions (Karydis 2011).

Gypsum-mortared brick vaulting developed in the Middle Ages in Spain, introduced from Morocco. More layers of bricks could be laid upon the first layer to add strength to the vault (depending on the

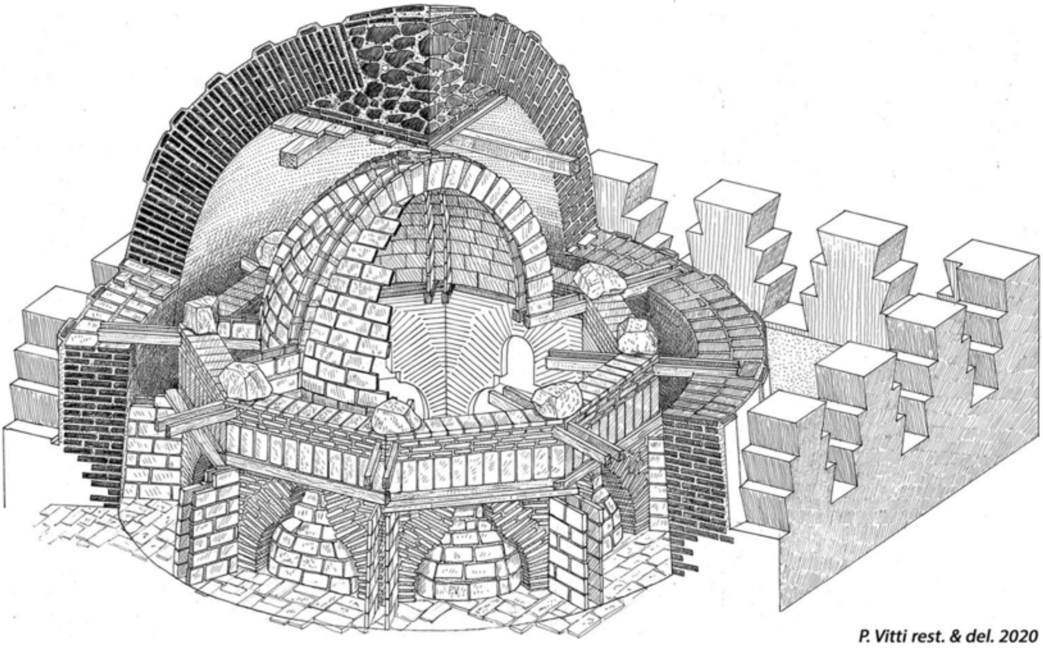

Figure 6. Cut-away axonometry of the two domes of the Qubba al-Barudiyyin.

span and required resistance). These additional layers did not necessarily use gypsum as bonding agent. These vaults proved to be lightweight and extremely resistant to stresses, as proven by the development of the technique in later centuries, and particularly by Rafael Guastavino and his son in the 20th century (Ochsendorf 2010). With the Guastavinos, tile vaults reached unprecedented dimensions, and so proved a competitive alternative to other vaulting techniques.

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History of Construction Cultures – Mascarenhas-Mateus & Paula Pires (eds)

Geographic and chronological extent of brick vaults by slices

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ABSTRACT: Vaults are built with vertical or slightly pitched bricks, in which each ring, arch or course forms a slice leaning against the one before, in such a way that no formwork is needed. Mud or lime mortars have commonly been used. Quick-drying gypsum mortar, used mainly in the Muslim world and in Al-Andalus, implies less difficulty in holding each piece together and gives rise to slightly different solutions. This technique originated in classical times and spread in the area that would later become the Eastern Roman Empire and Byzantium. Similar vaulting techniques can be found in Medieval Europe and North Africa. Many examples are known in the Iberian Peninsula dating from the 9th century onward. A particular type of this vaulting thrived in the bordering regions of Extremadura (Spain) and Alentejo (Portugal) during the early Modern Age. Following this expansion to the west, similar techniques have also been employed in Mexico up to the present day, probably introduced by Spanish builders.

1 INTRODUCTION

There are basically three ways of laying the bricks to build an arch or barrel vault. The bed or main plane may be arranged radially, towards the arch or vault axis, which is the most common bond. However, this can also be aligned with the vault surface, which gives rise to the so-called tile vaults or, alternatively, perpendicular to the axis. Here, we will deal with this last case in which the bricks, with their stretcher faces next to each other, form rings that constitute successive slices. Therefore, we call this arrangement "by slices", an expression similar to those used by the Spaniard Ger y Lóbez in 1869, "por hojas", and the Frenchman Choisy in 1876, "par tranches".

Bricks in vaults by slices are often not arranged vertically but with a certain pitch. The purpose of bonding the bricks by slices is widely agreed to be in order to avoid the use of formwork. During the building process every piece lean against the ones laid before and stay in place due to the adherence of the mortar, and that pitch helps prevent them from sliding. Other authors have thus referred to this technique as pitched brick vaulting. Lancaster (2010) calls the use of this term for both vertical and pitched bricks into question. On studying Roman architecture, she thereby makes a distinction between vertical brick vaults and pitched brick vaults.

Tile vaults are built quickly by "gluing" each brick header and stretcher face with gypsum mortar. Once hardened, this first layer is usually doubled by one or two more layers, and fixed with lime or cement mortar. Therefore, vaults by slices in which bricks are bonded with their headers inwards have a similar thickness.

2 ORIGIN OF THE TECHNIQUE. FRAMEWORK SAVING

This type of vaulting originated in Ancient Egypt and Ancient Persia. The well-known Ramesseum vaults were made of mud bricks bonded by mud mortar. The research team presenting this paper is currently investigating the variants of the technique in different places and times, so as to define relationships between focal points and compile a catalogue of historic types. In order to fulfil this task, we have gathered information about what can be found from Byzantium onwards. Cases from ancient times have been left aside because they are often vague and elementary and require some sort of archaeological work.

However, the technique had already gained a certain occurrence in Ancient Rome, in the area that would later become the Eastern Roman Empire, as Lancaster (2009) has shown. This author asserts that these vaults gathered the Parthian and Mesopotamian tradition due to the exchanges deriving from the war between Rome and Parthia in the 1st and 2nd centuries CE.

The study of Roman vaults by Lancaster (2015) leads to distinguishing between those with vertical bricks, barrel vaults in all cases, and those with pitched

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bricks, vaults generally composed of several segments or sections. This is a key difference for Lancaster, who states that in the first case lime mortar was used; hence avoiding formwork could not be the motive, as it must have been needed to prevent vertical bricks from sliding. Lancaster (2009) explains that holes in the wall that supports the vault can be seen in many of these cases —holes for laying the beams that would support centring frames. She also notes that these vaults' springings are often formed by radial courses of bricks while only the central part is built by slices. She concludes the aim of that is to hinder the development of the usual longitudinal crack in the central part, as there is no continuous joint likely to open. Although this hindering may be questionable, Roman builders might have thought that way, or might have preferred the central crack to divide into smaller ones in a certain area so that it would be less evident.

The formwork used might have been reduced to very weak circular forms, almost mere references for laying the pieces and just strong enough to support each slice (or two or three of them) as it was being completed. That would have meant a remarkable saving. Such centring could have been moved along the vault as it was being constructed. In fact, complete formwork with a continuous cylindrical cover might have been of little help for rapidly building a brick vault, as bricklayers would have to stand on it. Conversely, a light movable centring would let the workers stand in front of the vault's edge while building it. That would naturally involve some scaffold platform to walk on and stock materials, but not the complex timberwork required to support the whole vault weight, which would have been needed in the case of radial bricks. Scaffold platforms are known to have been a common device in the Middle Ages to stand on while building vaults. Furthermore, photographs by Fathy (1976) that depict the Nubian vaulting tradition show bricklayers on movable platforms. On the other hand, the use of different brick bonds at the springings and at the crown has been a common practice in every age. Either corbelled brickwork or radial coursing (as long as pieces do not slide) have been used up to a certain height to reduce formwork to a bare minimum.

In any case, the distinction pointed out by Lancaster is noteworthy. Arranging the bricks in perfectly vertical slices would require more careful work and a very adherent mortar. Roman vaults of this kind were built with lime mortar, which must have involved some kind of auxiliary means to prevent the pieces from sliding while laying each ring. For these completely vertical slices, gypsum mortar would have been more appropriate instead, as will be explained later. Precisely, Parthian vaults with vertical slices were apparently built with gypsum mortar (Lancaster 2009, 387).

3 LATE ANTIQUITY TO MIDDLE AGES DEVELOPMENT: BYZANTIUM

Brick vaulting by slices was brilliantly developed in the Eastern Roman Empire from the 4th century onwards, always with the purpose of avoiding centring. The varied arrangements of brick vaults by slices in Byzantium, and later in other Mediterranean areas, are particularly interesting because they show different ways of pitching the bricks and dividing the vault surface into segments so that the use of lime mortar is not a hindrance to applying this system. Had the bricks that form the slices been set with gypsum mortar, none of the Byzantine variations and later local developments would have taken place as they were aimed at supplementing the weak adherence of lime mortar. Gypsum mortar "glues" the pieces and makes it extraordinarily easy to set the bricks, just as happens in tile vaults, therefore different bonding experimentation is disengaged from performance requirements and thus formal effects can be searched for. Conversely, as Choisy (1876, 1883) brilliantly pointed out, the use of lime mortar gave rise to an interest in bonding experimentation in the first centuries of Byzantine masonry that can be explained from a constructive point of view. Choisy's explanation begins with the simplest case, barrel vaults, reporting two ways of pitching the bricks. One of them, known from Ancient Egypt and Persia, consists of flat slices of bricks (Figure 1A, B). Yet another which he finds in Byzantium consists of conical slices. In this way, the pitch angle of the bricks increases from the springings to the crown, and each conical slice forms a sort of splayed arch resting on those previous (Figure 1C). A variant of this system, probably very widespread, combines both ways, resulting in tilted conical slices (Figure 1D). In these Byzantine cases with conical slices, the mason builds

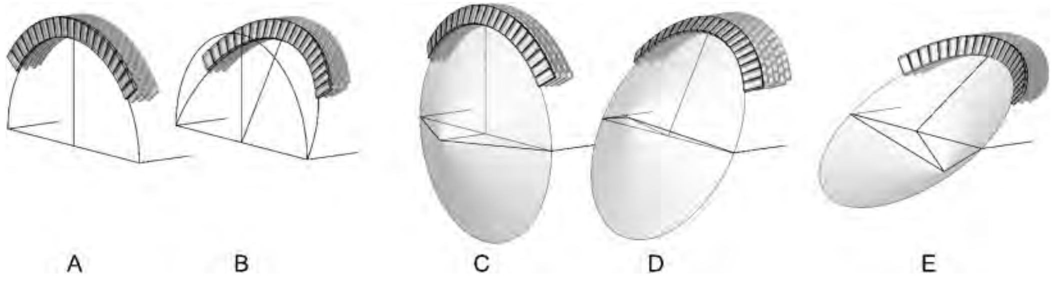

Figure 1. Different types of brick slice arrangement: A vertical slices; B inclined slices; C vertical conical slices; D convex inclined conical slices; E concave inclined conical slices (drawings by the authors).

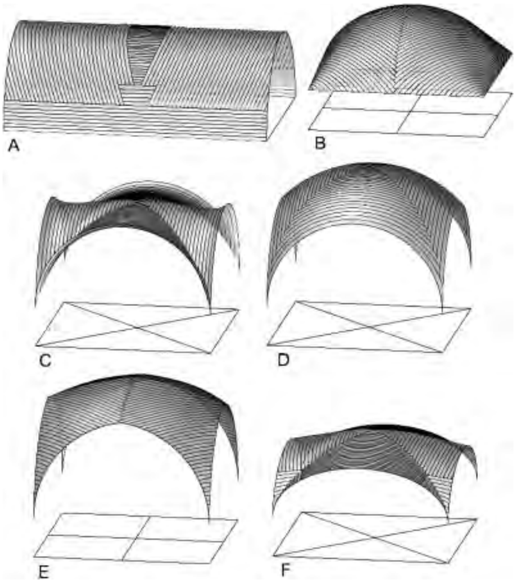

Figure 2. Some types of vaults by slices: A barrel vault with inclined slices; B from squinches; C Byzantine groin vault; D Byzantine sail vault; E from pendentives; F Extremaduran vault (drawings by the authors).

on the slices working from their convex part, the concave part therefore being the one which leans on the previous slice. According to Choisy, a light device made up of ropes and sticks could serve as a guide for laying the bricks.

Then, Choisy explains how the system adapts to cover square or rectangular floor plans. The vault is divided into four sectors or areas, each of them made up of brick slices. The elements needed to define the working process are the curves that follow the diagonal and perimeter arches, which are circumference arcs relatively independent from each other. Depending on how these elements are arranged, the shape of the resulting vault will be more or less similar to a conventional groin vault or to a sail vault (Figure 2C, D). This flexibility allows the vault to adapt to any rectangular or trapezoidal floor plan, and its central keystone height can also be adjusted to the convenience of each case (Figure 3).

4 OCCURRENCE IN THE MEDIEVAL IBERIAN PENINSULA

The Iberian Peninsula seems to be an important focus of this technique during the medieval period, and the existing examples allow us to study its development from early stages to the present day.

The springings of a vault similar to the Byzantine are preserved in the late Roman archaeological remains at Carranque (Toledo), and have been dated to the 5th century (Figure 4; García-Entero et al. 2014; López Mozo et al. 2020). Another paper presented to this congress shows a considerable number of sail vaults by slices preserved in the city of Toledo since the 9th century; so far at least 11 buildings have been located there with a total of 35 vaults of this type, including the mosques of Bab al-Mardum (Cristo de la Luz) and Tornerías. Many vaults similar to the Byzantine cases can be found in a wide horizontal strip in the southern part of the Iberian Peninsula, from the Mediterranean to the Atlantic. They date from the 11th and 12th centuries onward, but especially from the 13th century, and are frequently located in buildings linked to military orders (Molero Garíca et al. 2020). In all these cases, the mortar used appears to be lime mortar. Examples of brickwork arranged by slices can also be found in the webbing of ribbed vaults in this area, dating from the 13th century onward (Huerta 2017).

Figure 3. Hagia Sophia (photograph by Enrique Rabasa).

Figure 4. Remains in Carranque (photograph by Enrique Rabasa).

How this construction system reaches the Iberian Peninsula has not yet been defined. There are three possibilities. One possibility that cannot be ruled out is that it originated independently. As there are only three ways of arranging a piece of brick in a vault, as we mentioned before, all three must have been tested on many occasions throughout history, with different types of mortar; and so it would not be strange

Figure 5. Brick vault in the palace of the Sultan of Tlemcen, Algeria (photograph by Ignacio Javier Gil Crespo).

that the same system had been generated by what in biology has been called convergent evolution in different places, or that ancient traditions thrived independently in one place and elsewhere. However, the abundance of historical relationships between the peoples of the Mediterranean suggests that the success of a system could have easily extended from one place to another.

Another possibility is that the system may have reached Spain and Portugal through the Arab and North African world. This seems to be the case of tile vaults, the oldest example of which is found in the Almohad construction of Medina Siyâsa (Cieza, Murcia) (Almagro 2001), dating from the 12th century. Tile vaults spread during the Middle Ages to many areas, especially eastern Spain and the Kingdom of Aragon. A helical brick vault made of arched slices, which provides support to the staircase of the minaret converted into the bell tower of San Juan de los Caballeros de Córdoba, dates from the 10th century.

Vaults of vertical slices were built since the 11th century in Granada, at the Alhambra and its surrounding area (Almagro 1991, 232). Almagro (2020) mentions the expansion of this type in North Africa, in Jordan and Tunisia from the 8th century onwards. We have documented vertical slices in the central part of a brick vault with ring courses in the springings and haunches in the palace of the Sultan of Tlemcen (Algeria) (Figure 5).

These vaults have been built in Iran at least since the 11th century (Almagro 2020) and to date still are. All these cases appear to be bonded with gypsum mortar. If this were the path by which the technique reached the Iberian Peninsula, an important effort might have been made to create variants when instead using lime mortar, giving rise to different types.

A third possibility is that the Iberian Peninsula may have directly received the late Roman and Byzantine tradition. The Byzantine Empire was present in southeast Spain in the 6th and 7th centuries, with Carhtago Spartaria (Cartagena) as its main focus. Although we only know of cases of Byzantine vaults in the Iberian Peninsula from epigraphic documents, it cannot be ruled out that Byzantine builders established this technique in a region that already had an important Roman building tradition –no formwork vaults made of terracotta vaulting tubes are preserved, for example, in Complutum.

Figure 6. Above: Vaults of the pre-Absidian spaces of the church of the castle of Calatrava la Nueva (13th century). Below: vaults of Hagia Eirene in Constantinople (6th century). The similarity between the techniques is clear (photographs by Ignacio Javier Gil Crespo and Enrique Rabasa).

Although the cases dated before the 12th century are few and far between, from the 12th and 13th centuries onwards there was a spectacular development of the technique throughout the Iberian Peninsula, linked to the buildings of military orders, mainly castles and fortresses, such as Calatrava la Nueva (Figure 6), Montiel and Montizón. The similarities between the vaults of the military orders and the Byzantine lead us to imagine contact with the eastern and Byzantine world through the Crusades. While the Hispanic orders such as those of Calatrava or Santiago did not go on the Crusades, the Order of St John or The Hospital were closely related to the Kingdom of Jerusalem and the crusader movement. The exploration of this route might lead to an explanation for the adoption of this technique in other parts of medieval and Renaissance Europe, leading to new characteristic types, and combined with the particularities of

Figure 7. Vault of the Colegio de San Pelayo (University of Salamanca) showing the use of brick vaulting for the webbing (photograph by Enrique Rabasa).

Gothic construction (such as its application to rib vault webbing. Figure 7).

5 RELATED CASES IN LATE MEDIEVAL EUROPE

We have not found remarkable examples of post-Roman vaults by slices in Italy, apart from the very singular cases of the dome of Santa Maria delle Fiori, and some others with herringbone brick lines, although we are aware of their use in the fortress of Sarzanello (Ligura, late 15th and early 16th centuries) and some other cases further north. However, the webbing of German Gothic ribbed vaults is well-known to be often executed with bricks laid on courses that could be considered successive slices. The so-called diamond or cell vaults, a particular type of late-Gothic vaults mostly with no ribs, are also built by slices (Figure 8); a modern recovery can be seen in Thunnissen (1950). Wendland (2017) has studied the system in depth, correcting Ungewitter's explanations, and has even carried out some experimental archaeological trials (Figure 8). In these vaults, bricks become more inclined from the springings, where they are almost horizontal, to the crown. They also do so in semi-spherical vaults formed by inverted conical rings, which are more similar to vaults by slices in the central upper part (although the rings are compressed).

Vaults using the techniques described have been built in Eastern Europe, in Bulgaria (Sofía) and the present-day Romanian territories of Wallachia and Moldova (Comana, Bordeşti, Banloc, Iaşi and others; Figure 9), perhaps under direct Byzantine and Ottoman influence. In addition to these late-medieval examples, a Roman vault of this type, which has not been referred to so far, is also preserved in Romania at the fountain of the Roman castrum of Suceava. The tradition of decorating the interior of Orthodox churches with wall paintings may have hidden many other brick vaults by slices.

Late examples or those linked to folk tradition (17th–18th centuries) have also been found in Poland.

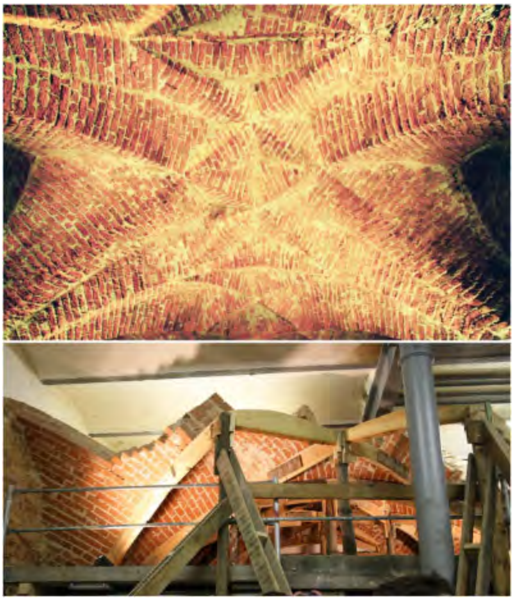

Figure 8. Above: Diamond vault at Trebsen Castle (Germany). Below: experience of reproducing it on a 1:1 scale in a workshop led by Professor David Wendland at the University of Dresden in the year 2012 (photographs by Enrique Rabasa).

Figure 9. Vault under the bell tower of Comana monastery in Romania (photograph by Ignacio Javier Gil Crespo).

The work of locating vaults by slices in Europe is progressively completing the map of the diffusion of this technique.

6 A PARTICULAR EARLY MODERN PERIOD OUTCOME. OCCURRENCE IN THE NEW WORLD

A particular type of groin vault by slices has been termed the Extremaduran vault (Figure 10). It is a surbased vault, with a radial course springing at the corners (Figure 2F), an arrangement that usually

Figure 10. Arch of Santa María on the walls of Cáceres (photograph by Ignacio Javier Gil Crespo).

extends to most of the groin, and with four cells made up of conical slices. These conical slices differ from the Byzantine in two important aspects: each conical slice rests on the previous one on its convex side and offers its concavity towards the place where the bricklayer is located (Figure 1E) and, in addition, the first slices that start from the walls follow inclined curves, for which a small triangular filling on each side is necessary (in Byzantium, this only happens in some of the barrel vaults). Some of these vaults are known to predate the 16th century. This particular type of groin vault by slices, which in Extremadura is called "de rosca", was described in 1883 by the Extremaduran architect Vicente Paredes (Rabasa et al. 2020), the same year in which Choisy's work on Byzantine construction was published (Figure 10). The details and building process are quite suitable for the construction of low vaults in dwellings, and so have they been used for centuries. Yet, we have also found examples with the same characteristics in Andalusia, in the south of present-day Castile and León (Figure 11), and in a great abundance in Portuguese Alentejo, although also in the Algarve and even in Lisbon. Therefore, this type might belong more to Portugal than to Extremadura. There are hundreds of them in the area known as "La Raya" on the border between Extremadura and the Alentejo (Figure 12, 13).

Vaults by slices are currently built in Mexico. According to Professor Alfonso Ramírez Conde, they follow a tradition originating in El Bajío, a central region of Mexico. In the town of Chiapa de Corzo there is a ribbed vault dating from the 16th century, with an octagonal plan shape and brick cells made by slices. It is well known that many Extremaduran men travelled to New Spain to work on construction sites. Extremaduran architect Francisco Becerra authored the cathedral of Puebla among other buildings and used brick in many of his works. There was no pre-Columbian indigenous tradition of building with fired brick, so it is most likely that the uses of Extremadura were brought to Mexico. The occurrence of vaults of this type in 17th and 18th century Mexican haciendas is yet to be investigated.

Figure 11. Puerta del Sol on the walls of Ciudad Rodrigo, by the military engineer Juan Martín Zermeño (photograph by Enrique Rabasa).

Figure 12. Current Mexican vault built by Andrés Flores Castañeda, 2020 (photograph by Andrés Flores).

Contemporary brick vaults by slices

In the Upper Nile, now southern Egypt, the technique was still in use in the 1940s, passed down from generation to generation of masons, according to Fathy (1948). Hassan Fathy carried out a formidable task for the appreciation and fostering of this ancient method of building. He especially focused on domes made up of annular slices and short-span parabolic barrel

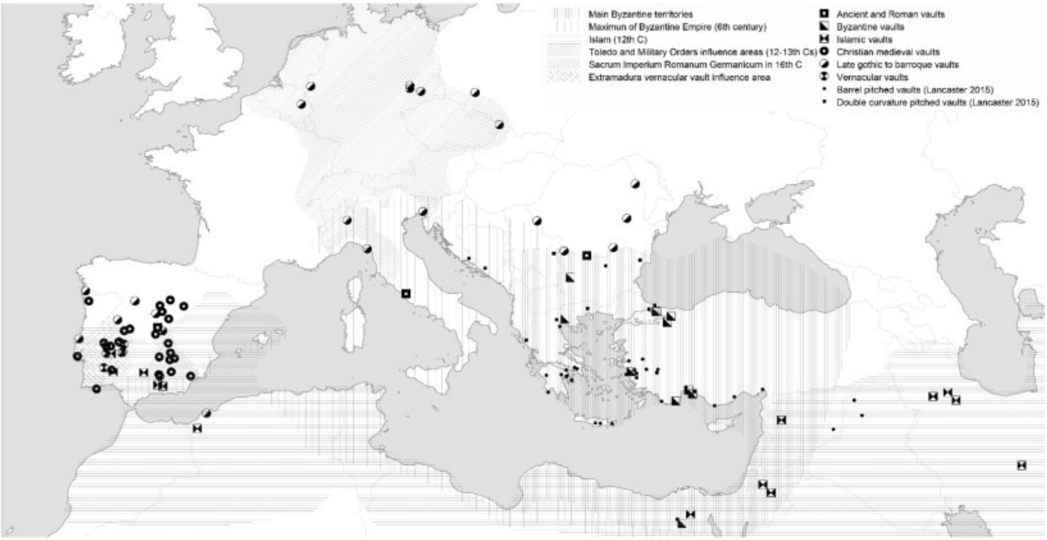

Figure 13. Synoptic map of the geographical and historical extension of brick vaults by slices. The map includes 246 documented cases in the Mediterranean area, Europe, North Africa and Middle East. The compilation method has mainly consisted of bibliographical research and field work with direct observation, together with computerized searches.

vaults, built with mudbrick (adobe) and linked to passive cooling systems and economic construction for people with limited resources.

Several initiatives have arisen after his work to use the so-called Nubian vaults in desert climates since the 1970s. Many of these are linked to self-construction and international cooperation, especially in the countries of the Western Sahel, where a number of NGOs operate. They often use adaptations and standardisations of the system that ease set-out survey and execution requirements for low qualified builders. There are also recent experiences in Europe and North America linked to the so-called ecological and bioclimatic architecture.

Alfonso Ramírez (2012) has called the vaults by slices “ladrillo recargado” (leaning brick), because each slice is supported by the previous one, and he is preparing a catalogue of vaulting masters who use this system at present. Their latest works are spectacular, pushing the possibilities of the system to the extreme (Figure 11). It is very often a question of covering a floor plan of existing bearing walls, so that the vault is supported by a horizontal polygonal line. In this case, the usual way of beginning the work is to start from the corners with a bond very similar to what Lancaster (2015) calls “by squinches”, which is extraordinarily old and has remained in use to this day (Figure 2B; see Ward-Perkins 1958). However, from these springings, the succession of slices can continue upwards to cover the space in many ways.

According to Alfonso Ramírez, two workers can cover four square metres in one day in the usual case of bricks laid so that their stretchers face the intrados. On occasion, their headers also do so, the vault thickness is therefore one foot.

7 CONCLUSION

Although it is not yet clear how the technique spread in some parts of Europe from the late Middle Ages onwards, it is possible to trace a path in the historical appearance of this type of vault, from the East to the Iberian Peninsula, and then passing on to America. In some places and periods, it seems that the system has been particularly successful, as in Byzantium, the medieval vaults in southern Spain, and the characteristic Extremaduran and Alentejo vaults in modern times. One of the most obvious moments of technical transfer is the transmission of Extremaduran traditions to New Mexico, but the details that would shed light on the expansion of the system there have not yet been investigated.

The variety of ways in which the bricks are arranged on the slices, and therefore of ways to form single or combined surfaces able to compose a vault, does not generally respond to mere decorative quirks but rather to the difficulty of keeping the brick in place during construction. Consequently, the choice of mortar type will be decisive as it must retain the piece while it is supported by the previous. Lime mortar does not have the adherence or speed of setting of gypsum mortar. Since this classification seems to clearly divide the different cases, attention should be drawn in future research to the different historical processes of making lime mortar able to accelerate its setting or to the mixing of lime and gypsum mortars.

The spread of the technique of vaults by slices from antiquity to the present day highlights the search for ways of saving time, material and cost in construction. Nevertheless, the technique does not transmit by itself. Tracking the route of its spread is to reproduce the paths that people followed with their knowledge, skills and ideas.

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On the origin of certain vaults without formwork: Iranian timbrel vaults

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ABSTRACT: The timbrel vault is a construction system that was widely used in the Iberian Peninsula from the late Middle Ages and from there spread to other European areas, as well as to the United States. However, the origins of this vault remain a matter of debate. Undoubtedly, its historical and geographical route is related to other construction systems that avoided the use of formwork such as leafed vaults, which were more abundant in different geographic areas and historical periods. In this regard, the study of some Iranian vaults that combine both procedures (timbrel and ribs of vertical bricks) is particularly interesting. They are, to our knowledge, the oldest examples of this construction technique. We analyse its early use as auxiliary means for the construction of the rest of the vault in which other materials such as adobe were used.

1 INTRODUCTION

Timbrel vaults were widely used in the Iberian Peninsula as a construction system. They were mainly applied in the vaults of churches from the Late Middle Ages onwards and reached maximum development during the 17th and 18th centuries. From this area of the Western world, the technique spread to other parts of Europe, such as southern France and Italy, and finally reached the United States towards the end of the 19th century. There has been a lot of speculation regarding the origin of the timbrel, and debate continues, even though there is a lack of information about its use in other areas of the Mediterranean and the Middle East. For some time, its genesis was considered to have taken place in eastern Spain in the 14th-century Gothic architecture of the region. This theory went hand in hand with its nickname of the Catalan vault, despite the fact that the earliest examples of such vaults are located in the region of Valencia, Spain (Gómez Ferrer 2003; Zaragozá 2012).

An early origin for this type of vault can be proposed after recent discoveries of specific constructions of this type in the Islamic architecture of al-Andalus and Northern Africa. These vaults could be dated as early as the 12th century (Almagro 2001, Almagro, forthcoming). Most importantly, these findings link these types of structures to a cultural realm that spanned a large area of the Mediterranean and the Middle East and integrated very diverse architectural traditions. From the 8th century onward, the Islamic world extended from the Atlantic to the Indus River, covering a wide range of territories and nations that soon became interrelated. Despite its early political fragmentation, established commercial and cultural relationships remained very active. This was due to two unquestionable and deeply intertwined factors: a shared language and shared religion. In fact, one of the precepts of Islam played a major role in the consequential exchange of knowledge that took place. The compulsory pilgrimage to Mecca favoured the mobility of people and, through them, of ideas and information. The importance of these journeys in the intellectual sphere is well documented. Doubtlessly, not only did learned peoples and intellectuals make this pilgrimage but members of other social classes also spent months and even years on this journey. This led to long sojourns in other cities and countries, during which many pilgrims worked for their sustenance before returning to their places of origin. This produced coexistence between people from different places that most certainly played a role in the spread of all forms of knowledge, in spite of the hindrances of political fragmentation.

The discovery of this type of construction in Islamic architecture leads us to search for its origins within the extensive territory over which Islam spread. A pursuit of this nature is not easy; first, because it covers a very large geographical area, and secondly due to the scarce research focused on the specific building techniques used for these vaults. We have found no mention of these vaults in any monographic works we have browsed on some of the buildings included in this analysis. Like other analyses that have preceded it, this one is based on the chance discovery of some examples in different places, and attempts to find relationships between them. We use the term chance discovery because, at the time, we were not specifically searching for this type of structure. Nevertheless, we have always held a subconscious interest in them, which made their identification easier.

Doubtlessly, the historical and geographical journey followed by this kind of vault is in line with that of other construction systems that do away with the use of formwork, such as vertically layered vaults, which were common in different areas and over many periods.

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Besides the absence of formwork, they both have in common the use of a crucial and almost indispensable material for their construction: gypsum plaster. Hence, the search had to focus on geographical areas and building traditions in which this material is widely present. This explains why, during a recent visit to Iran for reasons other than this study, we found vaults of this type that may reveal information key to solving the issue at hand.

2 THE VAULTS OF THE MASJID I-JAMI OF ISFAHAN

Among the vaults that we will analyse, the most interesting ones are unquestionably those in the Friday Prayer Mosque (Masjid-i-Jami) of Isfahan. This is not only because of the importance of this monument, but most significantly because a plausible chronology can be attributed to the building.

The Friday Prayer Mosque of Isfahan is among the largest in the Islamic world. It has had a long and eventful history, dating back to the first years of the Muslim conquest of the area, even though it acquired its current form mainly during the Seljuq period (11th century). The mosque contains a very wide repertoire of vaults. Among them, our attention will focus on two located to the north of the courtyard, near the iwan that opens onto that side (Figure 1).

These vaults were compiled in a thorough photographic inventory carried out by Galdieri (1971, photographs 168 and 170). One of the vaults was drawn in the photogrammetric survey of the mosque completed by Rassadiran Surveying Co. and published in the CIPA Symposium held in Tunis in 1984 (Rassadiran 1988: 238, Figure 21). However, neither publication mentions the uniqueness of this construction system. We were able to survey both vaults using a photogrammetric scanning technique with the Metashape software provided by Agisoft (Figure 2).

The vaults cover two sections of the prayer hall of the mosque. Both are noticeably square in plan, with an approximate distance between their axes of 4.20 m. They are supported by circular columns with a diameter of around 0.70 m and must be made of brick, despite their plaster finish. These columns are cylindrical. They lack bases and do not have entasis, possessing only a simple crowning element formed by a series of brick rows that serve as a transition from the circular to the square plan. They also support the arches that shape the spaces to cover in both directions. These arches are built with courses of vertical bricks joined with gypsum plaster. When this type of arch or vault is constructed attached to a wall, the first course adheres to the wall. However, in this case, they are freestanding. As such, the vaults were probably built using a simple formwork or truss made of wood or even of plasterboard to support the first courses. The next courses were adhered without the need for formwork as a support. The viscosity of the gypsum plaster adhered the bricks to the previous courses until the entire surface was completed. The elevations of the arches show a single ring of bricks. Its width is equal to the header of the brick. Each brick is almost square, measuring approximately 20 × 17 × 4 cm. Stretcher bond brickwork fills the spandrels up to the trasdos of the key; at the same height as the trasdos is a row of bricks that cantilevers outwards around 3 cm and serves to support the vault.

Figure 1. Timbrel vaults in the Friday Prayer Mosque of Isfahan.

These vaults take on the shape of cloister vaults with a pointed arch section that has four centres (Figure 2). They each have a span of approximately 3.40 m in both directions and ribs formed by three courses of vertical bricks. The ribs are located along the axes of the vault, while another two intermediate ribs in each direction are formed by two courses of bricks. Between these elements, which function as embedded ribs, the flat brickwork forms the timbrel vault. All the bricks have the aforementioned size, and they are placed in bands following the main axes of the vault. In the diagonal ridge, they form a mitre joint (Figure 3). Everything seems to indicate that the ribs were built first using the same simple truss employed in the arches. The remaining areas were filled afterward with flat brickwork. Therefore, the ribs helped define and control the shape of a vault that is far from simple since it has four centres.

The way in which the extrados of the vaults was executed is unknown since they are not visible. Whether

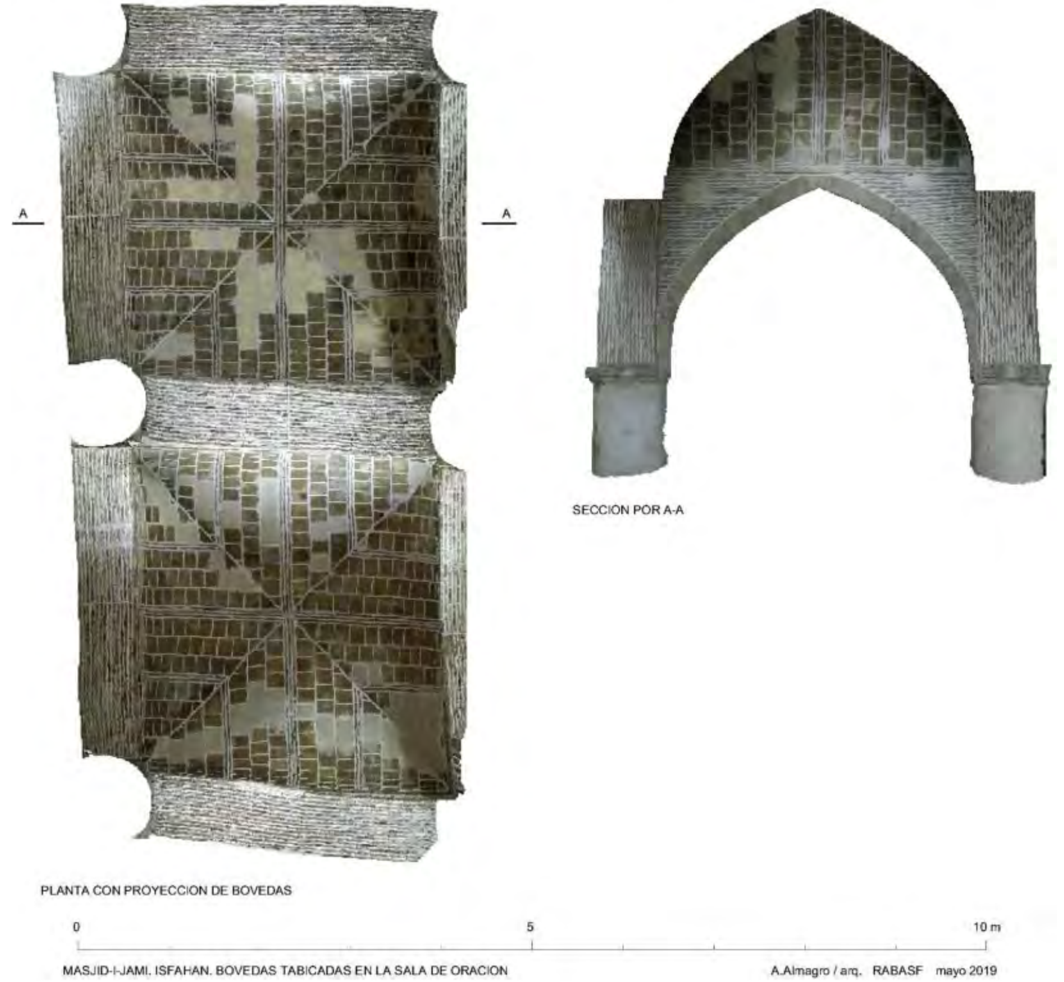

Figure 2. Plan and section of the timbrel vaults of the Friday Prayer Mosque of Isfahan.

Figure 3. View of one of the timbrel vaults of the Friday Prayer Mosque of Isfahan.

this was done with a second layer of bricks or with mortared rubble infill remains to be seen. It is important to point out that, with the exception of these two, the other, vaults covering similar spaces are laid radially, with the larger sides following approximately the direction of the curvature radii of the vaults. Therefore, each course is at least as thick as the header of brick; that is, around 17 cm. This contrasts with the mere 4 cm of the layer of the timbrel vaults. Photographs depicting the repair work carried out after the damages caused during the Iran-Iraq conflict show that these vaults are made of a single layer of bricks and an earthen infill (Kargar 2018: Figure 32). As we shall see in other cases, it is reasonable to think that, along their extrados, the timbrel vaults are clad with adobe bricks.

The rest of the vaults that cover the mosque have different shapes and designs. However, none of them were built using formwork or light auxiliary structures to sustain the first elements to be raised in the construction process. This makes it more difficult to control the final shape of the vault. In general, even though the bricks follow what seems like a radial layout, they are usually laid with a slightly lower inclination. This makes it easier to secure them in place during the

Figure 4. Timbrel vaults in the Yazd funerary complex.

Figure 5. Segmental timbrel vault clad with adobe bricks.

construction process, similarly to the process in which pendentive domes are executed (Figure 4, 5).

Even though this part of the mosque had already been built during the Buyid dynasty (10th century), it is more than possible that these vaults date to the building's restructuration during the Seljuq period (11th century). At that time, the mosque acquired the general layout we now see, with the four iwans opening onto the courtyard along their main axes (Kargar 2018: 34–36).

3 YAZD VAULTS

The presence of these vaults within a building with such a wide range of systems to cover spaces might lead us to think that this was just a unique exception. However, the existence of vaults with similar characteristics has been confirmed in the relative vicinity of Isfahan. Nevertheless, these other vaults are difficult to date since they belong to buildings that have not been studied. In this regard, an especially interesting case is that of the funerary complex known as the Towers of Silence. This complex is located to the south of the city of Yazd. These buildings were used by the community that followed Zoroastrianism or Mazdayasna, a religion that originated before the Achaemenid period. Around a dozen structures are strewn around the base of the mountain where the Tower is located. They served to accommodate groups from different tribes during funeral ceremonies. Most of them present a scheme that is common in Sasanian architecture: an open-ended central cruciform space covered by barrel or sail vaults and a central dome. Timbrel vaults lined with adobe bricks can be found within most of the buildings. This complex remained in use up until the beginning of the 20th century, making it very difficult to establish a precise date for the construction of these vaults (Figure 7).

As in the Isfahan mosque, the timbrel vaults are combined with arches and other vertical layered vaults. They adopt different formal solutions, among which the segmental barrel vaults and sail vaults stand out. (Figure 4). The segmental barrel vaults mostly cover spaces with short spans, such as passageways or small openings. They are always clad with a row of adobe bricks, the depth of which is double that of the bricks (Figure 5). The groins and the extrados of the vaults are filled in with the same material that makes up the adobes, thus presenting the appearance of a homogeneous infill. The use of plaster is limited to the joinery of the bricks that form the timbrel.

Sometimes the vaults are reinforced using ribs formed by bricks. These are laid vertically, normally in courses of two, and embedded into the width of the system (Figure 6). Since many of these buildings are in a partial state of ruin, they offer the possibility of observing how they were built. In many places, we observe that the timbrel vaults are formed by a single layer of bricks, even though they are clad with at least one more layer of adobe bricks (Figures 5 and 7). In some cases, they include ribs of vertical bricks to guarantee a better connection between the two layers of materials.

Although a more systematic study is still pending, at least for this central area of Iran, we were able to observe that this method of constructing vaults was present in more buildings than those we have mentioned. We propose that this technique was probably widely used, even in vernacular architecture. There are small vaults built to reduce the load of the groins of a larger vault among the ruins of a building in Yazd (Figure 8). In another case, the vaults give shape to the arches of the small windows of a lantern that tops a dome in the town of Nain, near its Friday mosque (Figure 9). These instances, together with other less significant cases, demonstrates that the construction of vaults and arches using flat laid bricks was part of a building tradition in central Iran as of ancient times.

4 CONCLUSIONS

The presence of timbrel vaults in Iran dating back to at least the 11th century raises the possibility that they originated in this area of the Middle East, where the use of gypsum plaster was part of the building tradition. Araguas (2003: 328) already posed this hypothesis without providing specific information. However, its origins might go even further back in time. In the

Figure 6. Sail timbrel vault with reinforcement ribs with two courses of bricks.

Figure 7. Springer of a timbrel vault clad with adobe bricks in the Mazdayasna funerary complex of Yazd.

mosque in Isfahan, there are elements of clear Sasanian tradition, such as the circular columns crowned with simple prismatic cymatia, the arches with vertical brick courses, and the springer of the arches and vaults in the form of a small cantilever formed by a simple brick (Reuther 1938–39: Figures 129, 133–4). It is precisely in Sasanian architecture that the first example of this building form can be identified: in the windows of the Taq i-Kisra or grand reception hall of Khosrow I (531–579) in Ctesiphon (Iraq) (Reuther 1938–39: 513, Figure 140). Despite its small size, the layout of the bricks that form the exterior arch giving shape to the opening follows the logic of this construction system (Figure 10). However, it is important to point out that this system was only used on the outer side of the window because the rest of the vault was built with vertical brick courses. In this case, it seems that the timbrel vault was used as an auxiliary method to facilitate the construction of the rest of the vault. It is illustrative to compare the layout of this arch with that of those in Figure 9 to appreciate the similarities between the construction systems used in both cases. They lead us to think that they both respond to the same construction method. The same happens with the vault shown in Figure 11. It belongs to the Shah Nematollah Vali mausoleum complex in Mahan, where the timbrel vault and the leafed arches are also used, although in this case, their function has been reversed.

All indications point to the idea that this way of laying bricks in arches and vaults was originally used as an auxiliary means to facilitate the construction of the main brick courses of these structures. This is evident in the timbrel vaults used as formwork for the formation of brick masonry or mortar vaults found in Almohad constructions of the 12th century (Almagro forthcoming). Even in examples from later periods, such as the 15th century, they were used in a similar way (Almagro 1981: 253). It is only after the 16th century and especially in the 17th and 18th centuries that

Figure 8. Small timbrel vaults lightening the weight off the groins of a larger ruined vault in Yazd.

Figure 9. Lantern crowning a dome in Nain with small timbrel vaults over its windows.

Figure 10. Window in the Sasanian Palace of Ctesiphon with timbrel arch and leafed vault (Reuter 1938).

Figure 11. Timbrel vault combined with a leafed arch in the religious complex of Mahan.

they became autonomous elements and played a main role as structural forms, reaching their undoubted climax in Guastavino's projects at the end of the 19th and beginning of the 20th century.

These Iranian vaults are part of a building legacy derived from the Sasanian tradition. This allows us to claim with relative certainty that this construction system may have originated in the Middle East, perhaps towards the 6th century, if not earlier.

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History of Construction Cultures – Mascarenhas-Mateus & Paula Pires (eds)

Types and uses of vaults and timbrel vaults in Interior Alentejo: Data for a typological study

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ABSTRACT: Vaults and timbrel vaults are one of the most particular construction techniques used in traditional Alentejo housing. To identify the vaulting solution types, this research deployed surveys of houses in four of the region's cities. The most frequent vault types are groin, trough, barrel and segmental, with lunette and sail found in smaller numbers. In the case of timbrel vaults, the most frequent shapes are trough and segmental. A correlation was found between the types of vaults and house divisions, their position inside the house and the geometry of rooms. The chronology of the spread of vaulting in the Alentejo's housing is still imprecise but may coincide with the early Modern Age evolution of housing typologies. The incidence of vaults also coincided with late 16th/17th century (and onwards) expansion of cities. The increase in recourse to vaulting solutions may also have been influenced by late 17th century military constructions.

1 INTRODUCTION

This paper presents quantitative and typological information on the usage of vaults and timbrel vaults in traditional Alentejo urban houses. The data was obtained within the framework of a larger research project on traditional urban housing in the Alentejo region, Portugal (financed by FCT – Portugal). The research combined architectural and photographic surveys of cases with archive information and inhabitant testimonies. A total of 507 cases were gathered from four cities of Alentejo – Estremoz, Borba, Moura and Serpa – of which 313 derived from direct architectonic survey and 194 from the private construction registers maintained by municipalities – 'processos de obras'. These are the records of building permits that include a description of the works, the property's location, a set of technical drawings detailing the existing situation and a second set with the proposed alterations. Additionally, historical information on housing characteristics was gathered from the archive documentation on the municipal estates of Estremoz in 1674 (Tombo dos Foros 1674) and 1746–1761 (Livro dos Tombos 1746–1761), property acquisitions in Borba from 1597–1883 (Livros de Notas – CNB 1597–1883) and the property record of the "Santa Casa da Misericórdia" religious organization in Serpa in 1673 (Tombo 1 – SCMS 1673). Out of the total sample, 106 houses display a given type of vaulting solution and therefore constitute the universe of cases addressed in this paper.

The geographic distribution of cases is divided between northern and southern Alentejo. Borba and Estremoz are located in the area known as the 'Marble Region' due to the existence of a marble stone anticlinal in north-eastern Alentejo, running between the cities of Évora (Portugal) and Badajoz (Spain). In turn, Moura and Serpa belong to the left bank of the Guadiana River, an area in southern Alentejo where the border line with Spain, which often runs along the Guadiana River, moves eastward to encompass land on both banks. This is one of the Alentejo areas where recourse to vaults is said to be more frequent (Keil 1961) (Table 1).

Table 1. The research sample of cases.

	Total houses	Houses w/vaults	Vaults
Estremoz	141	29	62
Borba	22	7	23
Moura	143	30	192
Serpa	201	40	167
Total	507	106	444

2 DEFINITIONS AND TIMEFRAME

It is important to begin with definitions. Vaults are the three-dimensional curvilinear self-supporting structures used as ceilings in construction. As the term encompasses a wide variety of types, this requires further definition. In this work, "vault" will refer not only to the structures built with bricks adjoining at their wider face, in any geometrical shape (Figure 1), but also to the set of cases whose construction system is

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Figure 1. Vault. Source: Rosado & Reimão Costa 2020.

Figure 2. Timbrel Vault. Source: Rosado & Reimão Costa 2020.

unclear or unidentified. In contrast, "timbrel vault" will refer solely to structures in which bricks are disposed with their wider side facing the vault's surface (Figure 2). Hence, "vault" refers to a group with both "vertical-brick" vaults and timbrel vaults even while the opposite is never true. Inside these two larger families, multiple geometries of vault co-exist. The types mentioned in this paper are barrel, segmental – based on arches of less than 180° –, groin, lunette, sail, and trough vaults (Figure 2), which references a type of vault – not common in the English language bibliography – similar to the cloister vault but where the four concave surfaces meet on a horizontal plane instead of at a point as they would in a cloister vault.

In Alentejo, the traditional housing construction techniques include a generalised use of earthen materials, particularly in the form of burned clay: hence, ceramic materials. Ceramics appear in the form of bricks, thin floor tiles or semi-cylindrical roof tiles. Bricks are used in masonry, often combined with stone, and almost always applied in the framing of doors and windows. In the northern areas of Alentejo, upper-floor structures are often made out of timber beams and joists covered by thin tiles of approximately 30 × 15 cm. In southern latitudes, there emerges increasing recourse to vaulting as a means of upper-floor support (Keil 1961).

Out of all brick's uses, vaulting is the most complex and erudite application found in common households. As mentioned above, both vaults and timbrel vaults appear in the Alentejo's housing, and with both traditionally plastered and whitewashed. This becomes problematic for cataloguing the vault types as identifying the construction technique employed depends on the opportunity for plaster-removing surveys – which, more often than not, cannot be carried out. The attractiveness of timbrel vaults is, nevertheless, easy to understand. The bricks being laid out horizontally means the quantity of material needed to complete execution is lower than that required by a vertical brick vault. This also enables a shorter execution time, given that the total weight and, consequently, the structural loads, are also lower. These lesser structural loads account for one of the key characteristics of the timbrel vault: the lack of any need for formwork in the construction process (Santos & Rocha 2000). All three factors contribute to cheaper execution costs for timbrel vaults and, given that economic rationale and material optimization are primal in traditional housing, it is natural that the timbrel vault option would be progressively favoured in this context.

While vaults are geographically widely spread, timbrel vaults are found in vernacular architecture only in some specific zones, as is the case with the southwestern Iberian Peninsula. The case is being made for the spread of the technique from Portuguese Alentejo to Spanish Extremadura in around the 19th century by emigrant mason workers (Carmona 2011). Nevertheless, the moment when timbrel vaults began getting incorporated into common Alentejo housing still remains unknown. As stated above, the identification of timbrel vaults is hard to accomplish without the removal of plaster, ensuring they often get mistaken for common vaults. In addition, the historical documentation does not distinguish between construction systems, making the geographical spread and dating of timbrel vaults even harder to define. While brick vault techniques can be traced back to Roman times (Ribeiro 1961), there are hitherto no records of any brick vaults in common homes prior to the Modern Age (16th–18th centuries). Conde refers to the use of roof terraces on common houses in the region in around the early 16th century but these vaults are associated with "edifices of prestige" (Conde 2011). Recourse to vaults in order to build roof terraces around this time frame is probable but, thus far, undocumented. The earliest references to common house vaults encountered by this research study date from the year 1673 in the city of Serpa. In 123 references, ten mention brick arches and five references refer to the existence of vaults (Tombo 1 & SCMS 1673). Of those, two are corridors and the remaining three references are ground floor

Figure 3. Roof terrace above a groin vault in Estremoz, construction attributed to c.1698. Source: Rosado & Reimão 2020.

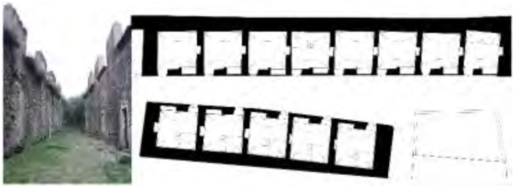

Figure 4. Barracks in Castelo de Vide – view and ground floor plan. Source: Rosado et al. 2019.

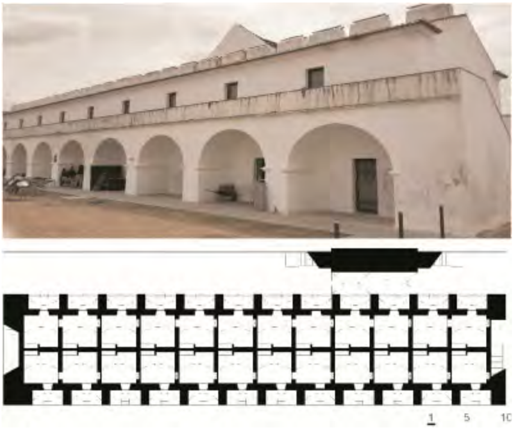

Figure 5. Barracks in Moura – side view and ground floor plan Source: Rosado et al. 2019.

rooms with dimensions of between 2.75 × 4.50 m and 4.50 × 4.50 m. All three compartments have another room above them (Figure 3).

Coincidently, in 1673, the border areas of Alentejo faced times of instability in between the “Restoration Wars” (1640–1668) and the War of the Spanish Succession (1701–1714). This post-Restoration war period would ensue a period of military fortification construction and experimentation that would last, intermittently, until the Peninsular War (1807–1814). Alentejo, given its flat and unimpeded border, underwent massive experimental military adjustments. As Conceição (2001) states, Alentejo would be continually under construction for the next two centuries. In the process of redesigning fortifications, one often overlooked piece of military equipment sprawled throughout Alentejo’s major fortified cities: the barracks. These barracks were built using the same techniques and materials as traditional housing, with the particular feature of using standard modular dimensions (Rosado et al. 2019). One type of barrack building with barrel-vaulted ceilings underwent implementation at the beginning of the 18th century, with examples including Elvas – Corujeira (1697) and Castelo de Vide (1714) (Figures 4 and 5).

Later, a more erudite type of barracks would be built in Moura and Almeida, with two floors of module-rows with barrel vault ceilings again used in the ground floor compartments.

Although this remains a matter for further documental research, the chronology of the dissemination of vaults in military residential buildings appears to coincide with the increase in their usage in traditional housing. Nevertheless, during the early stages of the Modern Age, traditional housing in Alentejo underwent a typological evolution with expansion in both area and height through merging smaller medieval plots and specially the construction of upper floors (cf. Reimão 2016). Whether there is a direct correlation, with the military architecture influencing common buildings, or whether the proliferation of vaults in traditional houses was part of a larger transformation in urban common housing, represent hypotheses for further research. What appears very probable is that vaults were used only residually in common housing prior to the 18th century, and there seems to be an increment in vault frequency from then onwards. In the example of Serpa, in 1673, there were five houses with any type of vault out of the 123 cases surveyed, a share of 4%. In 2019, 40 houses with vaults were identified, out of a total of 201 cases, a share of approximately 20%.

3 RESULTS

3.1 *Estremoz and Borba*

In the cities of Estremoz (Table 2) and Borba (Table 3) upper floor level vaults are rare. The tables identify a majority of cases on the ground-floor level and a decrease in recourse to vaults in the inner compartments of the house compared to the front divisions.

Table 2. Vault types and distribution in Estremoz.

Estremoz	*G	T	B	Seg.	L	Sa.	Tot
Ground Floor	24	7	14	7	0	0	52
Front Row	14	4	4	1	0	0	23
Hall	1						1
Shop	3		1				4
Winery	1						1
Multi-use room	3	3	2				8
Sitting room	2		1	1			4
Kitchen		1					1
Garage	4						4
Second Row	4	2	9	1	0	0	16
Corridor			1				1
Circulation			1				1
Shop	1						1
Winery	2						2
Multi-use room		1	3				4
Bedroom	1	1	2				4
Kitchen			2	1			3
Third Row	6	1	1	5	0	0	13
Corridor	2						2
Circulation				1			1
Sitting room	1		1	1			3
Bedroom	2	1		3			6
Kitchen	1						1
First Floor	1	5	0	3	0	1	10
Front Row	0	4	0	0	0	0	4
Sitting Room		2					2
Bedroom		2					2
Second Row	1	1	0	2	0	0	4
Circulation	1						1
Sitting/dinning room				1			1
Bedroom				1			1
Kitchen		1					1
Third Row	0	0	0	1	0	1	2
Kitchen						1	1
Bedroom				1			1
Total	25	12	14	10	0	1	62

*G – Groin; T– Trough; B – Barrel; Seg. – Segmental; L – Lunette; Sa. – Sail; Tot. – Total

Table 3. Vault types and distribution in Borba.

Borba	*G	T	B	Seg.	L	Sa.	Tot
Ground Floor	8	3	7	1	3	0	22
Front Row	4	1	1	0	0	3	9
Hall	2					2	4
Shop		1					1
Winery	2		1				3
Multi-use room						1	1
Second Row	4	2	3	1	0	0	10
Circulation			2				2
Shop	3	2	1				6
Multi-use room	1			1			4
Third Row	0	0	3	0	0	0	3
Winery			1				1
Multi-use room			1				1
Kitchen			1				1
First Floor	0	0	1	0	0	0	1
Front Row	0	4	0	0	0	0	0
Bedroom			1				1
Total	8	3	8	1	3	0	23

*G – Groin; T – Trough; B – Barrel; Seg. – Segmental; L – Lunette; Sa. – Sail; Tot. – Total

“Row” refers to the area between two load bearing walls, parallel to the façade. Hence, the front row consists of the rooms adjoined to the façade, the second row relates to the first inner compartments, and the third row often that next to the backyard (cases of more than three rows of compartments, vaults occurring in the fourth row – or in subsequent rows – are all counted as belonging to the third row). The incidence of vaulted spaces is higher in the front row, which corresponds to the most social areas of the house, indicating an association between vaults and displays of wealth. Moreover, the front row compartments were often those used when the house hosted trading activities open to the public, such as shops or wineries, which were commonplace in the Marble Region.

In Estremoz, the majority of houses with vaults are located within the castle walls (14 of 29) and the late 16th century-expansion downtown neighbourhoods (10 of 29). This duly notes that although the Castle is the oldest area of the city, it also remained the administrative city centre until the 18th century. In the medieval-origin residential neighbourhood of Santiago, recourse to vaults is scarce (5 of 29 houses). In Borba, 72% of the houses in which vaults were identified are located in the 17th and 18th century urban expansions, along the exit pathways of the city (Simões 2007). Furthermore, those found in older parts of the city correspond to wineries.

The usage of vaults in non-residential spaces accounts for 1/6 of the total cases in Estremoz, while in Borba, the sum of working compartments such as shops and wineries adds up to 11 cases of vaulted spaces out of a total of 23, reflecting the prevalence of vaulting in non-residential areas. Vaults are deployed

Figure 6. Winery in Borba – Groin vaults and brick arches. Source: Rosado & Reimão Costa 2020.

in combination with brick arches with the goal of achieving wide open spaces as seen in the wineries (Figure 6).

Vault ceilings appear in house transition spaces, such as corridors or rooms of passage referred to as “circulation”. These differ from corridors in the proportions of their room; whereas a corridor is much deeper than wider, in a proportion of at least 2 to 1, these “circulation” rooms are closer to a square shape with their dimensions similar to those of the other house compartments. Multi-use rooms refer to those where multiple activities take place as well as to rooms whose main use is unspecified.

Out of all residential rooms, the kitchen is that with the most specific function and related to manual labour. Kitchens are covered by simple and unornamented vaults, with the barrel and segmental types being the most common (4 out of 7). Overall, the most common types of vault found are groin, followed by barrel.

3.2 *Moura and Serpa*

The major difference emerging when comparing the tables above to those of Moura (Table 4) and Serpa (Table 5) is the significant increase of total numbers. This aligns with the mid-20th century observations that indicated this region to be one of the areas (or even the area) home to the most extensive usage of vaulting.

In Moura, 21% of the total cases have vaulting solutions. The greatest concentrations of cases occur in the city’s commercial heart, the neighbourhood known as ‘Arrabalde Novo’ whose origin dates back to the 15th century, and its southern expansion, dating to between the 16th and 18th centuries. In the older medieval-origin neighbourhoods, the application of vaults is sporadic (4 vaults in 20 cases analysed), while the ‘Arrabalde Novo’ they become standard, with 77 vaults counted only at the ground floor level and analysed in 27 cases in this neighbourhood.

Frequently, different vault and timbrel vault types co-exist inside the same building, as different ceilings are suitable for different spaces: barrel and segmental types, for instance, appear linked to deep rectangular rooms, such as corridors, with their dimensions varying from 1.30 to 1.90 m in width and 4.70 to 20.90 m in depth. Half of the barrel vaults identified (22 out of 41) in Moura cover corridors and circulation spaces.

Table 4. Vault types and distribution in Moura.

Moura	*G	T	B	Seg.	L	Sa.	Tot
Ground Floor	61	17	36	29	11	5	159
Front Row	30	9	5	11	7	3	65
Hall	8	4	2	2	1	1	18
Corridor	1	1	2	2			6
Shop	6			4			10
Multi-use room	10	2		2	1		15
Sitting room	3	2			1	2	8
Kitchen			1	1			2
Garage	2				4		6
Second Row	20	5	16	11	3	2	57
Corridor			6		1		7
Circulation	9	3	4	3			19
Shop	3						3
Multi-use room	5	1	4	3	1	1	15
Sitting room	1						1
Bedroom	2	1	2	4	1	1	11
Kitchen				1			1
Third Row	11	3	15	7	1	0	37
Corridor			4	2			6
Circulation	3	1	3				7
Multi-use room	3	1	4	3	1		12
Sitting room		1					1
Bedroom	1						
Kitchen	4		3	1			8
Garage			1	1			2
First Floor	10	8	5	5	2	3	33
Front Row	6	7	2	2	2	0	19
Corridor		1					1
Circulation		1					1
Multi-use room		1					1
Sitting Room	4	1	2		1		8
Bedroom	2	3		2	1		8
Second Row	3	1	3	2	0	3	12
Corridor			3				3
Circulation		1		2		1	4
Multi-use room						1	1
Sitting/dinning room						1	1
Bedroom	3						3
Third Row	1	0	0	1	0	0	2
Kitchen	1						1
Bedroom				1			1
Total	71	25	41	34	13	8	192

*G – Groin; T – Trough; B – Barrel; Seg. – Segmental; L – Lunette; Sa. – Sail; Tot. – Total

Table 5. Vault types and distribution in Serpa.

Serpa	*G	T	B	Seg.	L	Sa.	Tot
Ground Floor	71	22	14	33	6	1	147
Front Row	32	9	9	5	3	1	59
Hall	8	4	3	3	1	1	20
Corridor			2				2
Shop	10	1	1	1			13
Multi-use room	3	1	3				7
Sitting room	1	2		1	2		6
Kitchen	2	1					3
Garage	8						8
Second Row	29	10	2	17	3	0	61
Corridor				1			1
Circulation	7	3	1	6			17
Shop	6	1					7
Multi-use room	12		1	3	2		18
Sitting room	1	3		3			7
Bedroom	3	3		1	1		8
Kitchen				3			3
Third Row	10	3	3	11	0	0	27
Corridor			3	2			5
Circulation	2	1		3			6
Shop	2						2
Multi-use room		1		2			3
Sitting room	1						1
Kitchen	5	1		3			9
Garage				1			1
First Floor	5	8	1	0	2	4	20
Front Row	5	4	0	0	2	3	14
Circulation		1				1	2
Reception/Visits		1			1		2
Sitting Room	4	1			1	1	7
Bedroom	1	1				1	3
Second Row	0	2	1	0	0	0	3
Corridor			1				1
Circulation		1					1
Multi-use room		1					1
Third Row	0	2	0	0	0	1	2
Multi-use room		1					1
Sitting room		1					1
Kitchen						1	1
Total	76	30	15	33	8	5	167

*G – Groin; T – Trough; B – Barrel; Seg. – Segmental; L – Lunette; Sa. – Sail; Tot. – Total

From another perspective, of the 54 corridors and circulation spaces, ~41% of them are covered by barrel and segmental types (22 cases) and ~24% have groin vaults (13 cases). This appears to convey a correlation between deeper compartments and the barrel vault, whose geometry allows for limitless, one-direction expansion.

The same goes for the segmental type, which in Alentejo is almost always a timbrel vault, as the lower height structure of timbrel vaults allows for short rises, less than half the span.

Roughly a third (9 out of 34) of segmental timbrel vaults cover corridors or circulation rooms but, as the lower rise permits coverage of large areas without the floor height increasing excessively, they are more often applied in rooms whose shape more closely resembles that of a square (21 out of 34 cases). In parallel to that seen in the two previous cities, the kitchens are covered by simple types, with 7 cases of segmental and barrel vaults out of 11 cases.

Accordingly, the groin type interlinks with approximately quadrangular rooms, with an average side dimension of 4 m, rarely surpassing 5 m, either on the front row or in inner areas of the house. This also provides the most frequently found type, leading the count with a total of 72 cases. Particularly in the first row rooms of these buildings – the social spaces of the house, associated with guest-reception or compartments, such as stores, which are open to the public – the groin type is the most frequent (30 cases out of 65 on the ground floor; 6 cases out of 19 on the first floor).

Timbrel vaults, given their lower structural height, attain greater flexibility in terms of shape. One of the most common is the trough vault, where the edges arising in each corner blend in an almost planar surface. These serve to close square-shaped compartments, with angle irregularities of a greater or lesser extent and preferentially located in the front sections of the house. Some other hybrid types of timbrel vault appear as adjustments to the layout of rooms or as expressions of the masons' creativity, as identified on S. Pedro street, 50 (Figure 7). More complex timbrel vaults, such as the sail or lunette types, almost always appear in front row compartments, such as halls or sitting rooms, sometimes even decorated with stucco in naturalist or geometrical motifs.

The neighbouring city of Serpa repeats some of the trends observed in Moura. There is a high number of houses with vaulting solutions, 40 – accounting for 20% of the total cases. Nevertheless, contrary to Moura, the particular distribution is much more heterogeneous with cases equally found in the inner-wall medieval-origin centre and in the surrounding north-eastern (Santo António street), eastern (Largo do Corro) and south-western (S. Pedro street) 17th century neighbourhoods. It should be noted that Serpa's inner-wall centre, although of medieval planning, is still to this day the city's administrative and commercial centre with building reconstructions and updates therefore commonplace.

There is a clear prevalence of the groin vault, which might be explained by its usage in larger, more erudite houses, which naturally also contain a higher number

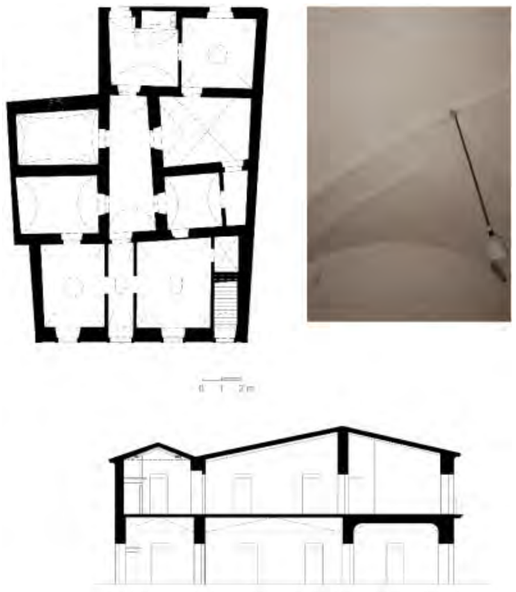

Figure 7. Moura – Rua de S. Pedro 50. Plan, vault detail, section. Source: Rosado & Reimão Costa 2020.

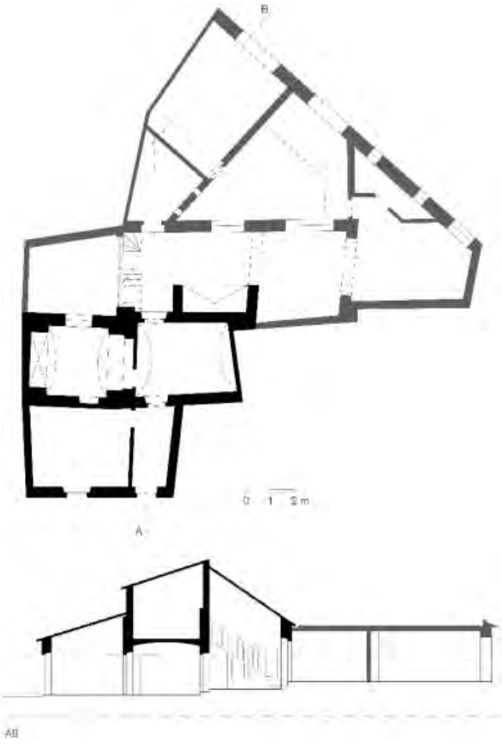

Figure 8. Serpa – Rua de S. Pedro 6. Plan, section. Source: Rosado & Reimão Costa 2020.

of vaults. One particularity of Serpa is the building of vaults on the upper floors to support terrace roofs; again, this feature is more often encountered in erudite housing (with two cases: one groin vault, one trough timbrel vault). In common housing, the sporadic appearance of a single vault on the ground floor seems to indicate former terraces in some cases but, given the expansion of this upper floors, these are nowadays hard to identify.

The association between barrel and segmental vaults and corridors and circulation spaces also clearly emerges in Serpa, with 45% of the barrel vaults and 36% of the segmental cases constructed in these compartments. The kitchens once again show a greater predominance of simple vaults such as the segmental (6 out of 16). While there are six cases of segmental versus seven groin kitchen vaults, four of the seven groin vaults report to the kitchen of the same erudite house, unbalancing the sample (kitchens almost always have only one vault). In that same erudite house, one upper floor kitchen features the only sail timbrel vault found in this room typology.

Once again, the majority of segmental and trough types are timbrel vaults, even if not all examples could be observed without plaster or measured in height. The foremost issue in estimating numbers of timbrel vaults in the Alentejo region interrelates with how many professionals assume a timbrel vault exists whenever a vault presents a low rise. However, vaults with vertically-laid bricks can also reach geometries close to planar, as displayed in Figure 6, making such an assumption incorrect. The identification of a timbrel vault needs validating either by removal of the plaster or by measuring the floor height in the building section when the survey can extend to every floor in the house (Figure 8).

4 DISCUSSION

The research presented here encountered four common vaulting solutions, two occasional types as well as sporadic hybrid geometrical applications. The most common type in the Alentejo traditional house is the groin type, by a wide margin, followed by the barrel, trough and segmental types. The lunette and sail types, although not rare, were reported in smaller numbers but still account for a transversal presence across the study area. The most frequent timbrel vaults in traditional housing are the low rise type, such as the trough and the segmental types, even while counting was restricted by the above-mentioned difficulty of identifying vaults rendered with lime-plaster. The literature had previously stated that the most common types of timbrel vaults were barrel and trough (Keil 1961) or simply barrel vaults (Santos & Rocha 2000) but had provided no sample or other numerical references. Even given the long time span lapsing, this research partly confirms the 1961 claims if, by *barrel*, the ‘Arquitectura popular em Portugal’ study means not only semi-cylindrical but also segmental vaults.

These findings report a correlation between types of vault and the function and shape of their rooms. The clearest example is the relationship between corridors and circulation rooms with barrel vaults and, to a lesser extent, with segmental vaults. Kitchens are the domestic space where vaulting appears in its simpler forms, with segmental types taking the lead. Groin and trough vaults associate with almost square-shaped compartments, regardless of their function. This also establishes a preference for more complex vaulting types in the front rooms.

One issue that remains open is that of the chronological dissemination of the vaulting technique and the emergence of timbrel vaults in the traditional house. While we may feasibly place the former, with some accuracy, as having occurred at the turn of the 17th century – a time when the common house is undergoing typological changes, such as its growth in height – the latter still remains a matter for further study. In three of the four cities analysed, the vaults display a greater incidence in the city areas corresponding to 17th century expansions, and appear in medieval-origin areas only when those maintained their administrative importance, such as around Estremoz Castle and Serpa’s inner-wall centre. Nevertheless, there is the belief that the documental sources can provide very useful information on both the generalization of the recourse to vaults in housing and the appearance of the timbrel vault. The immediate continuation of this research involves analysing the housing records akin to Tombo 1 – Santa Casa da Misericórdia de Serpa (1673) in the other cities of the region.

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History of Construction Cultures – Mascarenhas-Mateus & Paula Pires (eds)

Forging the link among shape, formwork, and mortar assemblies in Guastavino vaulting

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ABSTRACT: While the history of the Rafael Guastavino Company has been documented and studied to great length, the limited published research that is focused on the construction materials and assembly methods indicates that vaults were erected with minimal or no formwork, using tiles in combination with only gypsum mortar and Portland cement mortar. Physical evidence collected from a series of Guastavino vaults documented in this paper tells a much more nuanced story. It illustrates that the Guastavino Company significantly altered assembly methods, corresponding formwork, and adjusted binder materials as needed, based on the requirements of the individual project or even individual vault. This research presents a series of case studies and documents the mortars and types of formwork that were used in their construction

1 INTRODUCTION

While the history of the Rafael Guastavino Company has been documented and studied to great length, the limited published research that is focused on the construction materials and assembly methods indicates that vaults were erected with minimal or no formwork, using tiles in combination with only gypsum mortar and Portland cement mortar. Physical evidence collected from a series of Guastavino vaults documented in this paper tells a much more nuanced story. It illustrates that the Guastavino Company significantly altered assembly methods, corresponding formwork, and adjusted binder materials as needed, based on the requirements of the individual project or even individual vault. This research presents a series of case studies and documents the mortars and types of formwork that were used in their construction.

The Guastavino Company repertoire ranges from small-span vaults to expansive domes. The structures could be simple or complex, varying from barrel vaults with single curvature to domical vaults, domes with a small or large radius of curvature, arches, and spiral staircases (Figure 1). Vault shape, span, and finish varied depending on the type of structure and use. While Guastavino vaults are often load-bearing structures, a significant portion of them were also constructed solely for aesthetic purposes, supporting only their own self-weight (for example, vaults decorating the interior lobby of a steel-frame apartment building).

This variety of vault types forced the Guastavino Company to adjust their means of construction and erection sequence on a project-by-project basis.

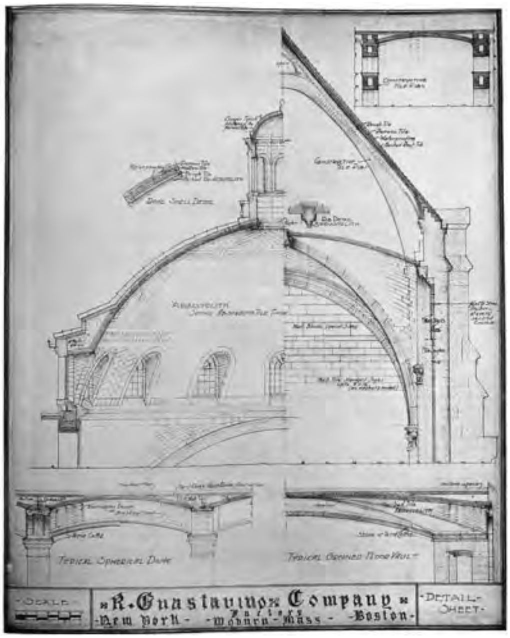

Figure 1. Guastavino advertisement in Sweet's Catalog (n.d.). Photograph by the author, Guastavino Fireproof Construction Company architectural records, 1866–1985, Avery Architectural & Fine Arts Library, Columbia University.

Though each project is seemingly unique, the company seems to have resorted to a "playbook," in which the design and form of the vault played a major role in influencing the mortar choices and use of formwork.

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Instead of employing a uniform set of materials and formwork in vault construction, the need for and type of formwork required was driven by an adept understanding of mortar properties and the form of the vault. Experience gained from an ever-increasing number of projects probably also helped refine how new projects were approached. This paper aims to clarify this interdependent relationship of vault form, use of formwork, and mortar selection in Guastavino vault assemblies.

2 NO TWO ARE ALIKE

In the last five decades, Guastavino vaults and domes have been the subject of fascination and study for architects, engineers, and preservation professionals. Very little research, however, has focused on the material composition of individual structures, or their means of construction. Most sources cite the absence or use of minimal formwork in the construction of Guastavino vaults or domes. Furthermore, these sources indicate that all structures uniformly use the same mortar materials of plaster of Paris and Portland cement mortar.

The basis for understanding the material composition of Guastavino vaults and domes originates from two major sources: an article written by Columbia University art and architectural historian George Collins in 1968 and a book written by Massachusetts Institute of Technology architecture and engineering professor John Oschendorf in 2010. These resources state that Guastavino domes were constructed using plaster of Paris at the joints of the first tile layer, with rough masonry tile added above in a layer of Portland cement mortar. For structures with decorative tile installed on the intrados, the finish tiles were pressed into place from below with a Portland cement mortar (Figure 2).

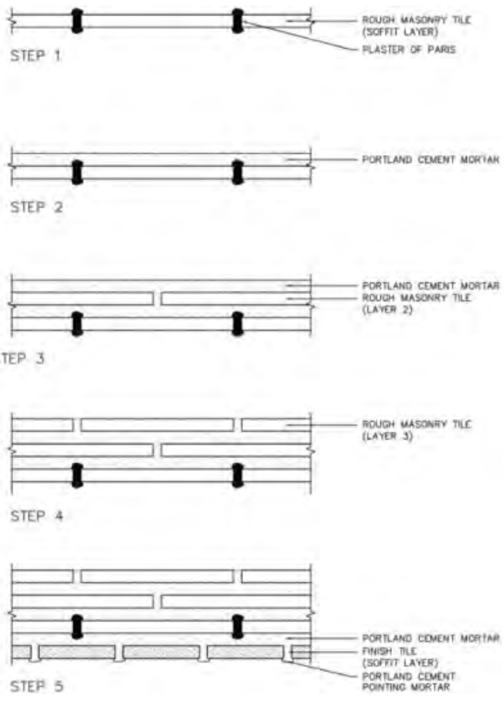

Figure 2. Assembly sequencing of Guastavino vault construction in Collins and Ochsendorf.

Our current research, based on both direct observation and data collected from design professionals who have restored Guastavino vaults and domes, indicated that other mortars and more robust means of temporary support (beyond light-weight formwork) were used in construction of domes and vaults.

The published accounts of the vault assembly and mortar composition are simplifications of a complicated construction technique. These vaults, when examined closely, are nuanced assemblies of tile and mortar. Even within individual projects, vault assemblies at different locations in a building can vary. This indicates that the construction methods and assembly of these vaults are more fluid than literature describes.

3 VAULT FORM

Physical remnants and archival evidence indicate that the formwork and the means of vault assembly were partially driven by the material limitations of the mortars used. For example, historical construction images of the crypts of the Cathedral Church of St. John the Divine in New York City show heavy timber formwork supporting Guastavino vaults in progress (Figure 3). Comparatively, a physical remnant of formwork at the Guastavino spiral stairs leading to the same crypts illustrates that lightweight wood formwork was applicable for certain conditions. At each of these locations, the mortars at the soffit level vary in color, hardness, and elasticity.

When individual structures are compared to one another, it is clear that a uniform set of construction methods were not applicable for all vault types. The control over material selection exercised by the Guastavino Company suggests the malleability of assembly

Figure 3. Construction progress image of the crypts of St. John the Divine. Guastavino Fireproof Construction Company architectural records, 1866–1985, Avery Architectural & Fine Arts Library, Columbia University.

methods and corresponding formwork. It also indicates the range of binder materials that could be adjusted to meet the construction sequencing requirements of an individual project or vault.

4 CASE STUDIES

To illustrate the interdependent relationship between form, formwork, and mortar assemblies, we selected two case studies: St. Paul's Chapel at Columbia University and the Cathedral Church of St. John the Divine in New York City. The mortars and types of formwork that were used in the construction of the tile structures at these two buildings are documented through archival and physical evidence. The case studies also identify a variety of assemblies erected at each building, further revealing the relationship of form, formwork, and mortar to the location-specific parameters of individual structures.

4.1 *St. Paul's Chapel, Columbia University, New York City, New York, United States*

The chapel was constructed between 1904 and 1907, and uses Guastavino vaulting throughout, including as the primary floor system, stairways, and the main dome of the chapel. The dome of the chapel is a double shell structure with a rough masonry tile exterior shell and decorative inner shell with tiles laid in the iconic Guastavino herringbone pattern.

4.2 *Outer Shell*

Both archival evidence and physical material were studied to determine how the dome was erected. Historical photographs revealed the use of heavy timber centering to shape the rough masonry tile exterior dome (Figure 4). This formwork had notably large spans between each guide.

Petrographic analysis of the mortar at the soffit layer (intrados) of the exterior shell identified the mortar as a pure gypsum. Literature most often ascribes pure gypsum mortar to the first tile layer of Guastavino vaults due to its quick-setting properties, which would allow masons to build rapidly with the use of minimal formwork. In this case, the quick-setting, relatively high-strength gypsum mortar allowed the tiles to span between the widely spaced guides of the formwork.

4.3 *Inner Shell*

Historical photographs of the inner shell construction were not discovered in our study. Physical evidence demonstrated that the soffit tile layer of the decorative inner shell was constructed first, meaning that the herringbone pattern was laid first – in contrast to the prevailing claim that the herringbone pattern is laid last (Figure 5). Archival documents did not indicate the type of formwork used in constructing the inner shell.

Petrographic analysis of the mortar at the intrados of the inner shell identified a gypsum-lime mortar. The use of this mortar in Guastavino vault assembly is previously undocumented. The presence of lime in a gypsum mortar would likely slow the setting of gypsum. It would reduce the strength of the gypsum mortar, but allow for increased pliability at the first layer. It would also affect the softness of the mortar, making it easier to rake out and install the typical raised finish mortar when vault construction is complete.

Figure 4. Construction progress image of outer dome of St. Paul's Chapel. Photograph by the author, Guastavino Fireproof Construction Company architectural records, 1866–1985, Avery Architectural & Fine Arts Library, Columbia University.

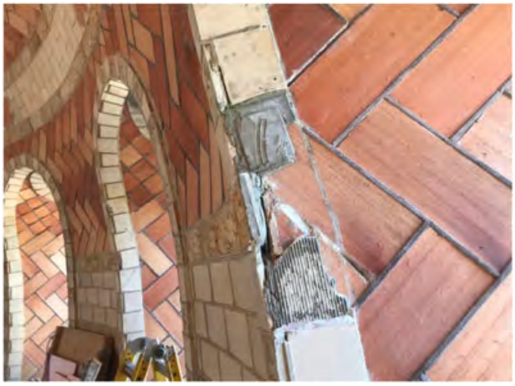

Figure 5. A finish tile removed at the soffit layer of St. Paul's Chapel inner dome reveals gypsum-lime mortar at the soffit tile joints. Photograph by Derek Trelstad.

At St. Paul's Chapel petrographic study identified four different mortars at the inner and outer shells. In addition to gypsum mortar and gypsum-lime mortar, natural cement mortar at the raised finish mortar at the inner shell and Portland cement-based mortar, as the primary bedding mortar, were identified.

4.4 *Cathedral Church of St. John the Divine, New York City, New York, United States*

The tile vaults in the crypts and at the spiral staircases at the Cathedral Church of St. John the Divine also reveal the relationship between the formwork and mortars. Similar to St. Paul's Chapel, Guastavino vaulting is used throughout the cathedral.

The Guastavino Company constructed vaults at the cathedral for 42 years, between 1898 and 1940. St. John the Divine provides a particularly interesting case study for Guastavino assembly because of this history and wide variety of assembly types; the vaults comprise the floor system throughout the chapel, stairs, finished ceilings, acoustical tile (Akoustolith), roof systems, and most notably, the dome at the crossing.

4.5 *Crypts*

The vaults in the crypts of the cathedral are a series of rough masonry tile vaults constructed in 1898. The vaults are set on top of tile arches (running north-south) and constructed with tiles laid in horizontal bands. Archival material was reviewed to assess the formwork used in constructing the crypts.

The use of heavy timber formwork is evident from these historical images (see Figure 3). The doubly curved vaults of the crypt have a particularly large span; approximately 15.25 m (50 feet) north-south for the primary tile arches across the nave floor and a 7.625 m (25 feet) span east-west between the arches. From construction photos, it can be discerned that the arches were constructed first, likely while being fully supported by relatively light lumber centering. (The lumber used in the centering for the arches was much smaller and lighter when compared to the heavy timber centering used for temporary support of the deep granite arches supporting the tile dome at the crossing.) Once the primary arches were constructed, tiles for the vaults were placed longitudinally along the arches using only simple formwork. The simple formwork was often single boards 25 mm × 200 mm (1 inch × 8 inches) with one edge cut to the radius of curvature of the vault (Figure 6).

In Figure 3, a mason standing on a raised timber working platform is placing tiles with their long side bordering the arches to create the vault. There are two or three primary guides spanning between the large arches that supported secondary forms parallel to the leading edge of the vault. The secondary forms were moved out along the primary forms as the vault edge was extended. The extensive formwork used for the primary arches eliminated the need for a quick-setting mortar as tiles were not cantilevering; the light primary and secondary formwork also provided support for the leading edge of the vault, allowing the use of a relatively slow setting Portland cement-based mortar in the first layer of tile. Because the crypt is not a public space, however, there was no need to be able to clean up or hide the soffit tile mortar.

Figure 6. Tile arches and vaults in the crypt of Saint John the Divine. The arches running left to right in the photo were constructed first, followed by the doubly-curved vaults. Photograph by Derek Trelstad.

Figure 7. Remnants of formwork at tile joints of spiral stair case at Saint John the Divine. Photograph by Erin Murphy.

4.6 *Spiral stairs*

At the rough masonry tile staircase leading down to the crypts, remnants of formwork give some indication to the methods used. Small slats of wood were installed at successive mortar joints (Figure 7). The mortar installed between tile joints was dark gray and extremely hard, which does not match the soft, brittle properties of a pure gypsum mortar typically expected at soffit tile layers. Lightweight guides were placed at each end of the tiles forming the spiral allowing a slower setting mortar, such as Portland cement to be used. While this approach is almost intuitive at a stair with a maximum plan dimension of 2.64 m (8 feet, 8 inches), it was also used at the dome at the crossing, where the span is 15.25 m (50 feet). Figure 8 shows lightweight forms tied through steel tubes embedded in the previously completed portion of the dome used to guide construction of the leading edge of the dome.

Testing of mortars at the stair and dome locations could not be conducted to identify the mortar composition. Visual and tactile properties of this mortar indicate that a Portland cement mortar was likely installed here as well.

5 DISCUSSION

The four examples of mortar types at St. Paul's Chapel and at the Cathedral Church of St. John the Divine illustrate the variety of mortars used and their relationship to the formwork and methods of assembly. These mortar types varied by the form and finish of different vaults. The use of a mix of centering and light formwork, at St. John the Divine, did not necessitate the use of a quick-setting gypsum mortar. Instead, a slower setting mortar, such as Portland cement mortar, was likely. Comparatively, the rough masonry exterior dome at St. Paul's Chapel employed the use of a pure gypsum mortar that could use lighter formwork and optimize speed of construction.

Figure 8. Construction progress photo of the dome at the crossing of St. John the Divine, July 16, 1909. Note the vertical form guides placed on the completed portion of the dome. Image provided by Episcopal Diocese of New York.

5.1 *Form-based mortar selection*

The Guastavino Company had a skillful understanding of the plastic and hardened properties of the mortars used in tile vault construction. In the *Essay on the Theory and History of Cohesive Construction*, Rafael Guastavino Moreno cites the need for a reliable, high-strength and fast-setting cement-based mortar, but states that a mortar of this kind does not exist. By understanding the qualitative characteristics and limitations of different mortars, the Guastavino Company was able to manipulate their materials to optimize construction (Table 1).

The research findings illustrate the link between form, formwork, and mortar. Based on these findings, it seems likely that mortar types were determined by their project- or location-specific use and the placement of formwork. For example, vaults erected with faster-setting mortars could use minimal, temporary formwork.

Slower-setting mortar required more extensive centering that could remain in place for days or weeks. These forms were likely more applicable for structural conditions with large spans, as seen in the crypts of St. John the Divine.

The addition of lime to gypsum mortar was not identified in the published literature before this paper. As the Guastavino Company, fiercely protective of its construction methods, did not mention the use of this material in their writing, the authors were only able to theorize why it would have been used. The theory that

Table 1. Qualitative Mortar Characteristics *, ** (Murphy 2020).

Type	Setting time	Compressive/ tensile strength	Elasticity	Plasticity	Water retentivity	Factors related to Guastavino const.
Gypsum (neat)	Minutes	Medium-high	Low	High	Medium	Water sensitive
Gyps. mortar (1:3 sand)	Minutes	Medium-high	Low	High	Medium	Water sensitive
Non-hydraulic Lime mortar (1:3 sand)	Weeks months	(Very) low	High	High	High	Sets only by carbonation; high shrinkage
Feebly hydraulic lime mortar	Week(s)	Low-medium	High	High	High	High shrinkage; high water retentivity
Eminently hydraulic lime mortar	Days	Medium-high	High	High	High	High shrinkage; high water retentivity
Natural cement mortar	Hour	Medium	Moderate-high	Low-medium	Medium	
Portland cement paste (neat)	Hours	High	Low	Low	Low	High strength
Portland cement mortar (1:3 sand)	Hours	High	Low	Low-medium	Low	High strength

* Mortar characteristics were assessed with relation to Guastavino vault assembly. Highlighted mortar types have been identified in Guastavino vaults. This table is a summary of mortar types that were available during the height of the Guastavino Company's work, based on an analysis of projects performed by the primary author. This table provides artificial constraints to mortar properties to simplify and compare these materials. Properties are simplified to compare notable characteristics of different mortar assemblies.

** Eckel's Cements, Limes and Plasters was used as a primary period reference in developing this table.

lime softened the gypsum mortar, made it more pliable and thus allowed for both easier working conditions, as well as to be raked out more easily appears to be the most feasible explanation.

The study of the vaults at St. Paul's Chapel identified the use of at least two mortars which have not previously been identified at other Guastavino vaults, natural cement mortar and gypsum-lime mortar. From the study, we also determined that mortar compositions varied. By using the table above, we can begin to formulate the Guastavino Company's design process. Mortar selection for Guastavino vaults was not a one-size-fits-all approach. Instead, mortars were determined by their plastic and hardened characteristics, and by the limitations of the vault's form.

6 CONCLUSION

The assessment of form and materials reveal the fluid nature of the process used to design and construct Guastavino vaults and domes. The use of formwork in Guastavino vault construction was driven by the project-specific limitations of mortar type and vault form. The variety of Guastavino vault forms indicate that there is a corresponding, varied approach to vault composition and assembly.

As many of these structures approach their centennials, repair and restoration will be necessary. An in-depth understanding of their materials and means of construction is vital to ensure the long-term preservation of these vaults.

There is not a one-size-fits-all approach for repair material selection. However, there appears to be a thread from building to building, and vault to vault, that can reveal the evolving construction methods of the Guastavino Company. By studying these structures and understanding their form, and documenting their assembly, we can begin to understand what mortars might have been used; and conversely, if we study the form and mortar types, we can hypothesize how the structure was constructed.

ACKNOWLEDGEMENTS

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Thematic session: Understanding the culture of building expertise in situations of uncertainty (Middle Age-Modern times)

History of Construction Cultures – Mascarenhas-Mateus & Paula Pires (eds)

A building expert without building training: The city of Lisbon vedor of works (14th–19th centuries)

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ABSTRACT: The role of the building expert has historically been filled by a person with building training, such as a builder (master-mason or carpenter), an architect or an engineer. However, in the historical Portuguese building world, there were some agents acting as building experts who had no formal construction skills or building practice as was the case of the *vedor* of works in the city of Lisbon. His expertise was the administration of building contracts for the city's public works. The aim of this study is, therefore, to bring to light the now extinct office of the city of Lisbon vedor of works, focusing both on the duties and on the men.

1 INTRODUCTION

On 13 November 1364, among the other people witnessing the act of property donation action in Lisbon was Lourenço Martins, identified as *vedor das obras do concelho* [-of works of the city] (Nacional Archive Torre do Tombo [hereinafter ANTT], *Mosteiro de São Domingos de Lisboa*, MS. 51, fl. 135–136v, Farelo 2008: 252). This reference to the office of *vedor* is probably the oldest known as no others have thus far been discovered in 14th century sources contrary to the case for the subsequent centuries. However, there is a strong likelihood that this municipal officer was instituted in the first half of the 14th century moreover in keeping with the appointment of many other office holders with the same designation.

Indeed, according to the legal historian Marcello Caetano (1985: 308), "the designation of vedor begins to be used at this time in the sense of a minister in charge of a government sector (*the one who sees* the issues around certain matters), perhaps in opposition to the *ouvidor* (*the one who hears* the parties in the judicial courts), thus outlining the distinction between administration and justice". Thus, several vedores were appointed within the royal court (Gomes 2003: 51–53). Some were entrusted with functions related to the general administration of the kingdom, such as the *vedor da chancelaria* [-of the chancellery], responsible for checking royal deeds and placing the royal seal, which appears in 1323 (Homem 1990: 100–110), and the *vedor da fazenda* [-of finances], responsible for the financial administration of the kingdom, already appointed and active in 1341 (Henriques 2008: 138).

Other royal vedores had, in turn, more circumscribed duties, such as managing properties or construction works. For Lisbon, documentary sources testify to the presence of a *vedor das obras do rei* [-of the king's works] in 1299, and a *vedor das casas e tendas do rei* [-of the houses and store premises of the king] in 1332 (Farelo 2008: 297, 752, 748).

In the 15th century, there was a multiplication in the vedores of the king's works. Appointed to act in a certain city, town or region, or even for a specific construction project, such as for walls, castles, fortresses, palaces or bridges, these officers were responsible for the administration and supervision of the construction works promoted by the king (see, among other sources, ANTT, *Índice da Chancelaria de D. Afonso V Comuns*, MS. 37, fl. 402v–404v). This movement was then followed by the institution of other related officers, such as the *vedor-mor* of the king's works and the *provedor* of the royal works, and a centralized structure for the management of royal works: the *Provedoria das Obras Reais* (Soromenho 1998, Senos & Silva in print).

It is, therefore, not surprising that some municipalities, particularly the larger ones or those with the greatest urban development, appointed similar officers to manage their own construction works. So it was in Lisbon; but was also in Oporto, where a *vedor das obras da cidade*, named Gonçalo Anes do Estão do Anjo, held the position in 1417 (Melo & Ribeiro 2011: 109). However, in smaller towns, that assignment could be carried out by existing municipal officials, especially the *vereadores* [councillors].

It should be noted, furthermore, that the medieval sources account for these two different officers (royal and municipal) with almost the same designation. For instance, in Lisbon, the municipal officer was the *vedor das obras do concelho*, while the royal officer could be called *vedor régio das obras* or just *vedor das nossas* [the king's] *obras da cidade*. This subtle difference is often perceived only in the context of documents, leading to some confusion and, perhaps for this reason, this topic has not been addressed by

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historians. Indeed, the only attempts to shed some light on the subject were made by Melo & Ribeiro (2011: 109–113), although within a broader study of medieval builders of Oporto and Braga, and more recently by Senos & Silva (in print) focusing on royal officers.

Nevertheless, nothing substantial has been written about this municipal officer of Lisbon, although the vedor of works is mentioned in the list of the municipal officers of many studies (for instance see Ferro 1996; Rodrigues 1968; Santos & Viegas (ed.) 1996). And yet, as detailed below, the vedor of works of the city of Lisbon was one of the first municipal officers to have their duties regulated in writing. Plus, as a building expert responsible for the contractual administration of the city's public works, it is surprising that those who held the office across the years never held any formal building training. This characteristic distinguishes them not only from other building administrators but also from other building experts usually identified in historic studies, such as builders (master-masons or carpenters), architects or engineers.

Thus, this study represents a first approach to the city of Lisbon's vedor of works, which falls within the scope of broader analysis about the officers related to construction works prior to the Liberal reforms instituted in the 19th century. Two aspects are particularly focused on: the duties assigned and the men who performed them. Therefore, in order to understand the office, the study covers a long timeframe, from the Middle-Ages until its abolition at the beginning of the 19th century. Due to the lack of previous studies, this makes recourse mainly to published and unpublished documentary sources above all from the Municipal Historical Archive of Lisbon [hereinafter AML-AH].

2 THE DUTIES

The scarcity of documentary references to the vedor of works of the city of Lisbon for the 14th century contrasts with that contained for the following century.

On 28 July 1421 and again on 23 March 1428, João de Évora, the city of Lisbon vedor of works, was one of the witnesses certifying two building contracts (AML-AH, *Livro 1° de Místicos*, doc. 12 and doc. 15, published in *Documentos*: 47–50, 55–56). The first contract, made between the municipality and two masons (Afonso Esteves and Lourenço Pires), covered work on the urban wall in the Cata-que-Farás area in order to settle a previous contract between the same parties that, according to the city council, had remained unfulfilled. The second contract, signed between the same municipality and one mason (Lopo Eanes), related to building a wall in the Santo Antoninho chapel.

In both documents, the clauses and obligations of the building contracts are described in detail. In the first contract, the masons had to supply a series of carved stones, set them in masonry according to the instructions given by the city's master-builder, make the plasterwork and foundations, hire the workers, as well as other necessary tasks. The municipality had to supply the lime for the mortar, the wood and the ropes for scaffolding at the construction site, and pay 650 *reais* for each built *braça* [fathom] in three parts, at the beginning, in the middle and at the end of the work. The work had to be completed by the following September on penalty of costs and expenses of 100 *reais* per day. The real estates of both parties served as guarantee.

In the second contract, the mason had to build a wall two fathoms high, with small windows nine palms high, in well-hewn lioz stone. He also had to extract the stone from the quarry and transport it to the construction site, to supply the lime and water, to engage workers and other necessary aspects. The municipality had to provide access to the quarry and pay 10 thousand *reais* for the work of extracting and transporting the stone, plus another 15 thousand *reais* for the other materials and works, also in three instalments. The deadline for completion was the following Christmas day on penalty of costs and expenses of 100 *reais* per day. The real estate holdings of the mason again served as guarantee.

The presence of the city's vedor of works certifying the conditions of these building contracts is not the result of chance as confirmed by several later documents that always connect this officer with this kind of duty.

In 1438, the Lisbon city council asked for royal permission so that, henceforth, the construction works undertaken by the municipality could only advance through the contract system [*empreitada*] by public auction, and not by daily fee [*jorna*] (on the difference between these two types of hiring a builder, see Pinto 2018a, 51–53). King Duarte granted this on the condition that the adjudication of the works was made in the city hall, in the presence of the councillors, the *corregedor* [a royal magistrate in charge of correcting acts in local justice and administration], the city registrar and the vedor of works of the city (AML-AH, *Livro dos Pregos*, doc. 327, published by Viegas & Gomes 2016; 468–471).

As happened on several occasions, a precept applied in the City of Lisbon became a rule throughout the kingdom (Caetano 1981: 79). Thus, in 1465, King Afonso V ordained by general law that construction works promoted by municipalities should always be carried out by *empreitada* in the presence of "the vedor of the said works of each place" (doc. published by Serra 1793: 394).

In the regulation establishing the remuneration for Lisbon municipality officers in 1471, the same king defined the following: at the beginning of each year, the members of the city council with the vedor of works and the *escrivão* [registrar] of the same works should tour the city to see what construction works were needed, such as walls, street pavements, spouts, drains or others, accompanied by builders to submit their prices for the building contracts, which should be written down by the registrar. It was the responsibility of the vedor and the registrar to check and supervise the works and the performance of the builders in order to verify the works were appropriately completed in accordance with the contract conditions and within the stipulated deadline (doc. published by Serra 1793: 422–426, AML-AH, *Livro dos Pregos*, doc. 482, published by Viegas & Gomes 2016: 591–593).

Ten years later, a new royal charter made it mandatory for masons and carpenters working on municipal works to obey the orders issued by the vedor of works, at that time Pero Vaz, who thereby held the same authority as the royal officer *almoxarife da tercena* [tax-collector of the shipyard] (AML-AH, *Livro dos Pregos*, doc. 445, published by Viegas & Gomes 2016: 562).

On 6 October 1484, all the duties of the vedor and the registrar of works were established in written form by the city council. Both officers had to witness the concession of the building contracts, and the registrar had to write them down in a log book. They had to continuously visit the construction site to check on the progress of work and to order whatever needed doing, with the registrar recording all the requirements and penalties imposed by the vedor. The vedor was in charge of the contractual obligations that belonged to the municipality, such as supplying materials and tools or transporting materials, having to buy or award them. All expenses had to be recorded in the book, from which a copy signed by both officers was taken and handed over to the municipal council. These same precepts also had to be followed whenever the vedor hired builders for daily fees. With the work completed, the vedor then had to place unused building materials and tools in the city's warehouse, paying for their transportation. The registrar had to record all income and expenses in the book, detailing the money given to the vedor and where it was spent so that councillors could ascertain the partial and the total costs of each work. The log book was to be verified each year to confirm the accounts. The vedor had to make all payments on a table installed in the city's warehouse, in which there was also the safe-box with two locks, with one key held by the vedor and the other with the registrar so that the safe-box could only be opened when both officers were present (AML-AH, *Livro dos Pregos*, doc. 471, published by Viegas & Gomes 2016: 580–582; and a partial copy in another city book, *Livro das Posturas Antigas* published by Rodrigues 1974: 163–164).

Through this regulation, the vedor of works clearly acted closely with the registrar, and both ran teams to coordinate, manage and supervise the development of the public works promoted by the city. While the registrar was responsible for recording all the relevant facts and payments, the vedor was the officer who acted on behalf of the city council to oversee matters of details during the execution of the works and to ensure that the technical, time and cost specifications were met in accordance with the agreed contract. In short, the vedor's expertise lay in the administration of building contracts.

On 30 August 1502, King Manuel I instituted the first legal document to regulate all the municipal officers of Lisbon. In this, the duties of the vedor and the registrar of works are dealt with in two sections: *Cap. das Obras* [Chapter of the Works] and *Veedor Escripuam das obras* [Vedor, Registrar of Works]. However, there were no substantial changes in the description of their duties, only fine-tuning, as is the case with the list of public works that these officers should take care of (now including walls and barriers, pits and gates, bridges, spouts, fountains, street pavements, drains and roads), and the monthly periodicity of the visit to the construction sites. In addition, clauses were added with a view to improving the performance of these officers, such as the requirement to schedule the works at the beginning of the year in view of the budget available, or the obligation to answer for failings resulting from their misconduct or negligence (AML-AH, *Livro Carmesim*, fl. 8v–28v, published by Santos & Viegas (ed.) 1996: 147–170).

In 1509, the same king arranged the three councillors of the city [*vereadores*] into three administration areas: meats [*carnes*]; sanctions and deeds to be dispatched at the Council Table ["*penas E feitos que se despacham na messa*"]; and city works and cleaning [*obras e limpesa da çidade*], "for each [councillor] to stay with the duties of their part, and each one deciding what he has to do, and not be in charge of all three" (AML-AH, *Livro Carmesim*, fl. 29v, published by Santos & Viegas (ed.) 1996: 171). This change gave rise to something that may be considered as the beginnings of the municipal works department. Due to the city's growth and the complexity of its administration, on 22 June 1591, King Philip II of Spain, I of Portugal, increased the number of councillors to six, which led to the subdivision of the works and cleaning area into two. This regulation (published by Sousa 1785: 124–136) clearly identifies how the councillor of works worked directly with the vedor of works, the registrar of works and the master-builder and also responsible for ensuring each fulfilled their duties. The following regulation of 5 September 1671 and the amendments made by the decree of 27 November of the same year, handed down by the regent of the kingdom, the future King Pedro II, complemented the earlier regulation but did not introduce any changes in this regard (published by Sousa 1785: 140–154, 320–321).

However, in the early-modern period, other related tasks were added to the duties of the vedor of works, although the main and most important duty remained administering building contracts.

One task deriving from the aforementioned subdivision of cleaning and works into two distinct administrative areas raised doubts about who was responsible for cleaning the city's fountains: whether the cleaning *almotacés*, who by regulation had to clean public spaces; or the vedor of works who, by regulation, had to repair the fountains. Thus, on 12 October 1596, the city council agreed this action should be carried out by the vedor of works because, when the fountains were not cleaned in due time, they would get damaged and then their repair would be more extensive and expensive. Hence, once a month, the vedor of works had to have the fountains cleaned, the cost for which would come out of the budget of the councillor of works (AHM-AH, *Livro 2° de Assentos do Senado*, fl. 65).

Other tasks were related to protecting the streets. Since 1504, the Lisbon city council demanded private individuals, before embarking on construction work facing the street, should made a request to the councillors to carry out a prior visual inspection, without which the building permit, mandatory since that date, would not be granted. However, it was only in 1592 and by royal provision, that this act was regulated: the inspection should be carried out by a commission made up of five municipal officers, who perform measurements and alignments in order to ensure that no public area was usurped, plus, the entire act should be recorded in writing. Although the vedor of works was not included in that commission, he started taking part in these inspections whenever the works to be built led to changes in the shape of the streets or in its pavements – since, by regulation, he was responsible for these kinds of works –, or whenever the works for construction were so important they required the presence of all municipal council members, a total of 23 people (Pinto 2016).

Moreover, since the city council agreement of 6 October 1690, the vedor of works was to confirm if the private ongoing works had the proper building permit and if the boundaries determined by the measurement and alignment actions were being observed, otherwise, he had the authority to impose an embargo stopping any further work and then to proceed against the offenders according to city bylaws (AML-AH, *Livro 5° de Assentos do Senado Oriental*, fl. 62v, published by Oliveira 1882–1911: IX 222).

Nine years later, on 13 February, the city council agreed that these building inspections also had to evaluate whether other neighbouring street-facing houses or walls in disrepair constituted a danger for the public good. In this case, the master-builders of the city should conduct an inquiry, then registered in writing (AML-AH, *Livro 5° de Assentos do Senado Oriental*, fl. 103, published by Oliveira 1882–1911: IX 522–523). Following notification by the inquiry certificate, the city council would act promptly and inform the owners of the derelict buildings to repair or demolish them. However, some owners appealed such orders in court, delaying the repair work and increasing the danger of collapse. For this reason, at the beginning of the 18th century, the councillors requested royal authorization to be able to demolish all buildings in imminent danger, even those propped up, whenever the owners did not comply with the demolition order within twenty-four hours. It was up to the vedor of works to carry out the demolition action against the will of their owners (AML-AH, *Livro 6° de Consultas e Decretos de D. João V do Senado Oriental*, fl. 57-57v, published by Oliveira 1882–1911: XI 23–24, see also Pinto 2018b).

The vedor of works also had responsibility for maintaining the fire extinguishing tools. This is known because in 1670 the city council asked King Afonso VI to order the royal officer in charge of the new fortification to deliver a set of tools for firefighting to the vedor of works. This request stemmed from the city no longer having such tools as less scrupulous people did not return them after fires had been put out. The king did not authorise this immediately and the council had to explain that the fortification works were stopped, those tools had been purchased through taxes imposed on the Lisbon's population, and the tools in question (namely, mattocks, pick-axes, hammers) were both used for building and putting out fires because they also served to dismantle walls and demolish buildings. Even so, the king only granted the loan of those tools for six months as the city council would have to buy new tools in the meantime (AML-AH, *Livro 4° de consultas e decretos de D. Afonso VI*, fl. 463–465v, published by Oliveira 1882–1911: VII 193–194, 197). In order to avoid the new, recently acquired, tools going missing, the city council made a specific regulation on this matter, assigning and listing which of the municipal officers, masons, carpenters, sawyers, hewers and other masters kept certain tools, such as axes, picks, hoes, buckets and lanterns. However, the city also had new equipment, such as nozzles, ladders, ropes and others, which were stored in two specific houses. These tools should only be delivered to specific people when a fire broke out. After the fire was extinguished, the vedor of works was to check whether those tools had been returned, acting against anyone who had not done so (doc. published by Oliveira 1882–1911: VII 54–57).

Finally, between 1719 and 1755, the vedor of works was assigned yet another task. He had to manage the making of new awnings, colonnades and other removable structures for the Corpus Christi procession, and store all those things in the city's warehouses. As this task was not his direct obligation, it was remunerated for separately, also accumulating the title of *almoxarife da colunata* (AML-AH, *Livro 1° de Consultas e Decretos de D. João V do Senado Ocidental*, fl. 228–230 and *Livro 2° de Consultas, Decretos e Avisos de D. José I*, fl. 95–104v, about these ephemeral structures, see Raggi 2014).

However, in the wake of the 1755 earthquake, the vedor's duties became residual where not even irrelevant as the king had removed the jurisdiction for the reconstruction plan of the destroyed area and the urban management of the surviving remainder from the city council (Monteiro 2010: 189–206). Only with the administrative and judicial reforms of the Liberal era (particularly the decrees of 16 May 1832) did the Municipality of Lisbon recover part of the city's urban management, despite the fact that it was still shared with the central government's Public Works Department (Silva 1997: 276–280).

3 THE MEN

While the regulation of 1484 is very detailed about the duties committed to the vedor of works, it says nothing about who should hold the office or for how long. The oldest information in this regard dates back to 1433. The city council complained to the king that many municipal officials – giving as an example precisely the vedor of works – started to occupy the office permanently through requests, pleas and favours, contrary to the ordinance that established the service time of just three years. The king ordered the old system be kept, adding that only for the benefit of the city could someone stay in office longer, which should be elected and chosen with royal approval (AML-AH, *Livro dos Pregos*, doc. 320, published by Viegas & Gomes 2016: 444–451).

The lack of data does not allow us to truly assess this point as from the middle of the 14th century only five names of vedores of works are found in the known documentary sources: i) Lourenço Martins in 1364 – aforementioned; ii) João de Évora in 1421 and 1428 – aforementioned; iii) João Aires in 1433 – witnessing a certified copy of documents (AML-AH, *Livro 1° de D. João I*, doc. 16); iv) Estevão Vasquez in 1437 – referred to in a royal charter (AML-AH, *Livro 2° de D. Duarte e D. Afonso V*, doc. 16); and v) João Gonçalves in 1452 – witnessing a rental contract (AML-AH, *Livro 1° de Emprazamentos*, doc. 12).

However, from 1481, and perhaps even before that, and for another 22 years, the office was held by Pero Vaz –aforementioned –, although it is not known whether he remained in office for such a long time due to appointment renewal or by donation (on ways to access public offices, see Hespanha 1982: 384–403). Contrary to what one might suppose, Pero Vaz was not a builder nor did he have any construction training. He was, in fact, a knight of the royal house and so had some social prestige and authority. Furthermore, he also had some wealth as in 1485 the city council tried to make a deal with him (by leasing tax collection) to obtain the money necessary for drainage works in the Ribeira area and, in November 1486, he offered to lend the city 100 thousand *reais* to repair the wall that had collapsed next to the royal ovens – a work that had been ordained by the king three months earlier (AML-AH, *Livro 2° de D. João II*, doc. 34, 52, *Livro 1° de Provimento de Ofícios*, doc. 37). Plus, as a member of the royal house, he also communicated directly with the king, having been summoned by King João II, in 1487, to commission the works on the fountain *del-Rei* [-of the king] (AML-AH, C*ópia* do *Livro 1° do Provimento da Água*, fl. 10v-11, *Livro 2° de D. João II*, doc. 83). In 1492, the same king issued instructions on how to manage the money for the city's works, sending the city's *corregedor* to speak to Pero Vaz, who was to adjudge which works were most needed (AML-AH, *Livro 3° de D. João II*, doc. 44). In 1493, Pero Vaz wrote to the king alerting him that the halt in the paving work on Rua Nova was due to a royal order that prevented the caravels of Cascais from transporting the stone, after which the king ordered the municipality to buy two boats for that same purpose. Two years later, the king ordered that a fine paid by an apothecary (a total of 100 *cruzados*, circa 38 thousand *reais*) be entirely applied to that paving work and thus handed over to Pero Vaz (AML-AH, *Livro 3° de D. João II*, doc. 53, 56, 87; about this paving work, see Gonçalves 1995). In 1497, Pero Vaz complained to King Manuel I that the administrator of the All-Saints Royal Hospital (which was under construction) obliged the city works builders to work on the hospital. In 1500, by royal order, Pero Vaz was in charge of the construction of the city's new wharf. And, in 1501, he became involved in a dispute with a schoolmaster over the transportation of stones for paving the streets. Additionally, in 1502, he participated in settling the compensation for the houses the king had ordered demolished (AML-AH, *Livro 1° de D. Manuel I*, doc. 17, 47, 60, 66B). Within the city council, Pero Vaz replaced the city procurator at a document certification in 1486 and for several rental contracts in 1502 (AML-AH, *Livro dos Pregos*, doc. 453, published by Viegas & Gomes 2016: 569–570, AML-AH, *Livro 5° de Escrituras de Aforamentos*, fl. 48v–51v, 56v–57). He also participated in drafting two bylaws, one concerning the transportation of olive-wood in 27 November 1495, and the other on the running of bulls in the city streets in 15 May 1503 (*Livro das Posturas Antigas* published by Rodrigues 1974: 213–214, 264–265).

Marcos Mendes took the place of Pero Vaz, having witnessed many rental contracts between October 1503 and March 1504 but of whom nothing else is known (AML-AH, *Livro 5° de Escrituras de Aforamentos*, fl. 175–208).

However, shortly afterwards, the office of vedor of works was held by a particular person: Diogo Brandão. The city council gave him the office after the death of his father, Pedro Brandão, in 1510, while holding the office. However, Diogo Brandão was a minor and his mother requested the king's permission for the office to be temporarily held by his uncle, Álvaro Fernandes, until Diogo attained adulthood. The city council must not have been pleased with the proposed name, having instead chosen Estevão Gonçalves as, in April 1511 he already appears as vedor of works (AML-AH, *Livro dos Pregos*, doc. 500, published by Viegas & Gomes 2016: 609–610). Such a choice forced the king to intervene again, instructing the council to let the heirs appoint the substitute (AML-AH, *Livro 1° de Provi-mento de Ofícios*, doc. 126, 129). The outcome of this question is unknown but what the sources show is that Diogo Brandão was in charge of the office from March 1521 (AML-AH, *Livro de Festas*, fl. 56–78v). However, there is no building work associated with his name with the available documents only mentioning that he was a witness to legal acts in 1522, 1527 and 1532, or that he had leased buildings belonging to the city in 1539 and 1540 (AML-AH, *Livro 2° de D. João III* doc. 8; *Livro das Posturas Antigas* published by Rodrigues 1974: 316–318, *Livro 4° da Vereação*, fl. 142–142v, *Livro 1° de Tombos Antigos*, fl. 36, 55). Nevertheless, we may accept he was responsible for maintaining the new walls built along the river in the Ribeira area according to the royal decision of 22 February 1521 (AML-AH, *Livro 4.° de D. Manuel I*, fl. 151).

Francisco da Silva was the next officeholder at least since 1544. This is known because in 1556 he requested a salary increase stating that he had held the office for twelve years and that the growth of the city had increased his work and expenses, forcing him to have two horses and servers to do the job (AML-AH, *Livro 2° da Vereação,* fl. 95v–96). In the same year, he checked the cleaning work in Rossio and made a contract with carpenter António Paulo for work on Paço do Alqueidão (AML-AH, *Livro 3° da Vereação,* fl. 90, 95). He additionally received good news in 1560, when notified of royal confirmation that his office, which had been donated to him by the city council, was lifelong and heritable, thus able to appoint a son or daughter as his successor (ANTT, *Chancelaria de D. Sebastião e D. Henrique,* MS 5, fl. 8v). Henceforth, the office of city of Lisbon vedor of works became the property of his family, always passing from father to son, although occasionally the office might be, as did happen, rented by other people (on the ownership of offices, see Stumpf 2014).

The first heir of the office was Lucas da Silva (Francisco's son), who also held the title of noble-knight of the royal house. In 1579, he was already identified as the vedor of works but nothing is known about his actions only that the city council, in 1594, ordered him to encounter the city's weights and measures that had gone missing (AML-AH, *Livro 13° de Escrituras de Aforamentos*, fl. 42–44, *Livro 2.° de Assentos do Senado,* fl. 47v).

On the next vedor, Francisco Tavares da Silva (Lucas' son), the information is even scarcer. From later documents, it is known he held the office but it must have only been for a short time because in he was beheaded in 1615 for having killed his wife, Brites de Gouveia (Secco 1880: 256). The couple left a minor son, Miguel Nuno da Silva, who was at risk of losing ownership of the office were it not for the intervention of his maternal grandfather, Miguel Nuno de Gouveia, who enjoyed a good reputation in the city for having served as a literate judge in various municipal courts. The trouble arose from a legal action brought by João de Sousa Pereira who claimed the office for himself. In the end, it was agreed that João de Sousa Pereira would serve as vedor of works until Miguel Nuno da Silva was old enough to do it but also until another municipal office was provided for him (AML-AH, *Livro de Quitação e Desistências*, fl. 136–137, *Livro 3° de Assentos do Senado,* fl. 80v–81v).

In the 1625 list of the municipal officers needed for the municipal service and public works, and for such reason discharged from military service, Miguel Nuno da Silva already appears as the city's vedor of works (AML-AH, *Livro 1° de Filipe III*, fl. 72–72v). With King João IV in the throne – which ended the period of Spanish rule (1580–1640) – in 1641, Miguel Nuno da Silva was awarded the habit of the Order of Christ with a pension for his services in the fortification works (but also for services done by his father during the siege of Mazagão in 1562 and by two uncles in India). Six years later, he received another pension for having given the city flag to General Álvaro de Abranches da Camara and city keys to the king, on the day of the king's acclamation (ANTT, *Registo Geral de Mercês, Portarias do Reino,* Ms. 1, fl. 73v and Ms. 2, fl. 93v–94). In 1658, he applied to the Inquisition Court in Lisbon to be an associate member [*familiar*] (ANTT, *Tribunal do Santo Oficio, Conselho Geral, Habilitações, Miguel,* mç. 20, doc. 315); and still held the office of vedor of works in 1664 (AML-AH, *Livro 2° de Consultas e Decretos de D. Afonso VI,* fl. 357, published by Oliveira 1882–1911: VI 498–499).

His son, Lucas Tavares da Silva, also received the habit of the Order of Christ in 1647 for having joined the Armada of 1646 and having proffered to go to Brazil with Count António Teles de Menezes to repel the Dutch attack on Bahia (ANTT, *Registo Geral de Mercês, Portarias do Reino*, Ms. 2, fl. 94). He stayed several years in Brazil, where his son, Francisco Tavares (Coutinho) da Silva, was born.

For this reason, in the last years of the 17th century, the office of vedor of works was not performed by its rightful owner but by other people who rented it. Since 1674, the vedor was Pedro da Cunha de Almada, who worked on three wharves (S. Apolónia, Fundição, and Belém), on the demolition of the city gate of Mouraria, and on the widening of Rua dos Ourives de Prata (AML-AH, *Livro 6° de Consultas e Decretos de D. Pedro II*, fl. 282–287v). In 1685, although the office was already owned by Francisco Tavares da Silva, it was served by Cosmo Saraiva de Andrada who, due to illness, delegated it for six months to António Salter de Macedo (AML-AH, *Livro 9° de Consultas e Decretos de D. Pedro II,* fl. 78–83v). And, in 1696, another office server, Vicente Pereira de Castro, placed an embargo on a private work (AML-AH, *Livro de Cordeamentos 1637*–1715, fl. 297–300v). In the early 1700s, the office owner, Francisco Tavares da Silva, also imposed several embargos but, due to illness, he passed on the office to his son, Lucas Nicolau Tavares da Silva, having requested this of the city council in July 1705 (AML-AH, *Livro de Cordeamentos 1637*–1715, fl. 89–90v, 146–147v, 236–237v, 234–235v, *Livro de Cordeamentos 1669*–1704, fl. 355–356v, *Livro 19° de Consultas e Decretos de D. Pedro II*, fl. 216–217v).

Lucas Nicolau Tavares da Silva became the city's vedor of works in office for the longest time: 31 years. Indeed, between 1707 and 1738, he received several orders from the city council to fix river walls and other public buildings, to clean fountains, to check buildings in danger of ruin, to work on the Corpus Christi procession, but above all to make and fix the pavements of several streets and roads (AML-AH, *Livro 4° de Registo de Cartas do Senado Oriental*, fl. 1, 4v–5v, 7v, 13, 21, 29v, 56v, 58–58v, 60–62v, 70–71v, 73v–74, 78v, 92v, 95v, 97, 100–102, 143, 148–150v, 170, 177–178v). In 1737, he asked the city council to authorize his eldest son and rightful successor in office, Miguel Nuno da Silva Azeredo Coutinho, about eighteen years of age, to accompany him in the exercise of his office. Two reasons were invoked: so that his son could begin to learn the office that would eventually be his and so his son could replace him when he was unable due to the ailments that he was suffering. Furthermore, this appeared a common practice as he gave many concrete examples where such authorization was granted, including the case of his own father (AML-AH, *Livro 12° de Consultas e Decretos de D. João V do Senado Ocidental*, fl. 60–63v). Both the city council and the king gave the requested authorization, however, in the last years of his life (between 1740 and 1751), Manuel Clemente served in the office in his place (AML-AH, *Livro 16 Consultas e Decretos D. João V*, fl. 85–90v, *Livro de Folhas de Ordenados a Cargo do Recebedor da Fazenda da Cidade 1751*, fl. 94).

Miguel Nuno da Silva Azeredo Coutinho started in office in 1751 but was on the verge of losing it due to a deal made by his father years earlier. Indeed, Lucas Nicolau Tavares da Silva contracted a debt to Arcângela de Mendonça, giving ownership of the office as a mortgage and, due to the lack of payment, the lender sought to recover the amount owed by selling the office at auction. However, Miguel Nuno da Silva Azeredo Coutinho appealed to the king, who authorized him to use his salary as vedor of works to pay off the debt over the next nine years (AML-AH, *Livro 2° de Consultas, Decretos e Avisos de D. José I*, fl. 95–104v, *Livro 3° de Consultas, Decretos e Avisos de D. José I*, fl. 10–13v, 266–267v, 280–283v, *Livro 4° de Consultas, Decretos e Avisos de D. José I*, fl. 12–13v, 24–25v). In 1753, he received another royal mercy: the authorization for his uncle, Carlos Manuel Tavares da Silva, to replace him in office, without salary, since he suffered from a disabling disease (AML-AH, *Livro 4° de Consultas, Decretos e Avisos de D. José I*, fl. 192–195v). All these events must have made the city council's members uncomfortable in such a way they changed his seat on the council table to place him further back. Miguel Nuno da Silva Azeredo Coutinho then complained to the king about that but was not as successful as on other occasions as, according to the city council, the change made was not intended to disregard the office or the officeholder but rather to end with a privilege. They explained that the place he used to occupy (at the top of the table to the right of the mayor, on the registrar's seat – see the table schema in Ferro 1996, 79) had been an inadvertently tolerated abuse as he was not a true member of the city council but an inferior and subordinate officer (AML-AH, *Livro 7° de Consultas, Decretos e Avisos de D. José I*, fl. 217–238v). In 1786, he asked to be replaced by his son, Lucas da Silva de Azeredo Coutinho, for health reasons (AML-AH, *Livro de Decretos de D. Maria I*, fl. 4–7v).

Lucas da Silva de Azeredo Coutinho became the last owner of the office of vedor of works in 1789, after his father's death (AML-AH, *Livro 2° de Avisos de D. Maria I*, fl. 36). However. it seems that he never practiced it. Having graduated in law from the University of Coimbra in 1782, and a knight of the Order of Christ since 1793, he held other important positions throughout his life: Bairro do Mocambo criminal judge (1786–97), *provedor* of orphans and chapels (1797–1803), high judge of the Court of Appeal of Porto (1800–05), high judge of the Court of Appeal of Lisbon (1805–14), crown procurator assistant (1810–21), tax procurator for the Tobacco Administrative Board (1814), appeal high judge of the Court of Appeal of Lisbon (1814–21), crown procurator (1821–23), high judge of the Royal Supreme Court (1823), counsellor (1824), chancellor of the Three Military Orders (1832) (Arquivo da Universidade de Coimbra, *Índice de alunos da Universidade de Coimbra, Letra C, Lucas da Silva de Azevedo Coutinho*, ANTT, *Mesa da Consciência e Ordens, Habilitações para a Ordem de Cristo, Letra L*, mç. 12, n. 22, Subtil 2010: 394). Nevertheless, it is not known who rented the office during this period only that Manuel Cipriano da Costa was serving in this role in 1831 (AML-AH, *Coleção de Editais da Câmara Municipal de Lisboa, 1828–1835*, doc. 93).

The almost nonexistence of mentions to the city's vedor of works in the late eighteenth and early nineteenth centuries resulted from the aforementioned change in Lisbon's urban management after the great earthquake. However, it is also true that since the mid-18th century, there were concrete measures to end the ownership of public offices (Subtil 2012: 71–72, Estorninho 2014: 152–155), something that ended up openly declared in the first Portuguese Constitution of 1822: "public offices are not owned by anyone" (*Constituição*: 9). The combination of a new notion of public servants with the Liberal reforms of 1832, which profoundly altered the organization of public administration and the structure of the municipal councils, led to the only possible outcome: the abolition of the secular office of vedor of works of the city of Lisbon.

4 CONCLUSION

Notwithstanding the fragmentation of data for many years, the examined documents provide an overview of the office of vedor of works of the city of Lisbon; a municipal office that emerged in the first half of the 14th century and lasted until the beginning of the 19th century.

From the start, by representing the city council, his core duty was to coordinate, manage and supervise the financial aspects and the development of the public works promoted by the city, having received other related tasks throughout the early-modern period. Working closely with the registrar of works, and, from 16th century under the direct control of the councillor of works, his expertise encapsulated the administration of building contracts.

The importance of this office can also be gauged by the values earned: the annual remuneration was the fourth-highest paid, only overshadowed by the mayor, councillors and city treasurer; and of the emoluments for building inspections, it was the second-highest paid, below the councillor of the works and at the same level as the city procurator (Ferro 1996: 58–59, Pinto 2016: 276).

However, the city council never picked a builder, an architect or an engineer to carry out such a vital role in the public works. Instead, from the biographies of the vedores, we may grasp how these men must have had other qualifications. They had to be able to read and write in order to check the clauses and obligations in the building contracts and sign off the works reports, despite being assisted by the registrar who, of course, had also to be literate. They should also have some economic means not only to avoid being tempted to get rich at the expense of the office and damage the public accounts but also, if necessary, to lend their own money to pay for building services or materials. They should also occupy a high social position, courtiers or preferably members of the nobility, not only because they needed to exercise authority over the builders or owners of ruined buildings and to act on legal nonconformities, but also because they met with the highest magistrates in the city (the councillors) and with the king himself. Likewise, the men who rented the office to occupy it for some time should have the same qualifications as the officeholder, and/or should already have held other positions in the municipal council.

In this sense, the absence of technical building training – as also happened to most vedores for the king's works and *provedores* of royal works (Senos & Silva in print) – would be supplanted by the personal and moral qualities, in addition to the fact that the practice of the office would give them the knowledge and skills necessary to exercise it. Furthermore, with the ownership of the city of Lisbon's office of vedor of works in the same family, the expertise to perform it would easily be transmitted from father to son since the latter usually began in the office by accompanying the former in his later years. On the other hand, the vedor of works had the assistance of skilled builders (as technical building experts) to estimate the prices for the building contracts or to assess the lack of stability of rundown buildings.

Only in 1852, following the founding and organization of the Ministry of Public Works, Commerce and Industry and its district departments, responsible for managing public works and for assisting municipal councils in this matter, did technical building training become mandatory to perform these kinds of duties. Indeed, from then on, the administration of public works building contracts, with specific regulations enacted 1856, deepened in 1861, and improved in 1887, was only to be carried out by the most reputed and skilled construction professionals in the country at that time: the director-engineers of Public Works (*Collecção: ano de 1852*: 383–384, 513–516; *ano de* 1856: 128–135, *ano de* 1861: 93–98; *ano de* 1887: 200–205).

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History of Construction Cultures – Mascarenhas-Mateus & Paula Pires (eds)

Maintaining/repairing Paris through expertise (1690–1790)

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ABSTRACT: After defining the concepts of building repair and maintenance, our work on the exceptional collection of building appraisals in early, modern Paris enables us to understand how experts used them to conserve, enhance, and maintain the capital and its real estate heritage. From a technical point of view, what circumstances called for repair: the detection of a defect, the appearance of deterioration, the risk of harm? From an economic point of view, how did experts evaluate the cost of repairs, either those to be undertaken or those already carried out, and what impact did these two types of repairs have on the value of a property? From a legal point of view, did surveyors make use of customary precepts to divide the financial burden of the maintenance work? We will show that, while the profitability of a property was often the main justification for repairs, comfort and the safeguarding of heritage were also significant factors.

1 INTRODUCTION

In recent decades, the maintenance and repair of buildings have become essential concerns of our contemporary societies as we search for more sustainable practices. Too often, we forget that these practices are not new. The analysis of a coherent and complete collection of construction appraisals carried out between 1690 and 1790 clearly demonstrates that, since the 17th century, the question of repairs has occupied a central place in the “policing” of the city, private property law, and construction practices. Buildings are built, of course, but more importantly they are repaired, with a view to counteracting the natural ageing process or even the effects caused by the actions (or inactions) of man. Surveyors are called upon to evaluate not only the cost of future repairs, but also the cost of repairs that have already been carried out. They are often required to do this in very varied situations, ranging from estimating the value of a property to assisting in a neighbourhood dispute over a common wall. What is meant by the terms “maintenance” and “repair”?

From the entry for “entretien” (maintenance) in the *Dictionnaire historique de la langue française* (Rey 1998) we discover that, beyond its first modern meaning (attested since c. 1450) of an “exchange of words”, from the 16th century (first attested in 1578) it took on an additional meaning of the action of maintaining something in the same state. This meaning was based on the verb “entretenir”, attested since the end of the 14th century, meaning “to keep in the same state, to make last, to maintain”. By metonymy, the noun subsequently extended to cover “the care, repairs, etc.” that are required for this action of maintenance. Etymologically, the word “réparation” (repair) is similar to “maintenance”. It is borrowed from the low Latin derivative *reparatio*, the “action of re-establishing, of renewing”. As is often the case (and just as for “entretien”), the word followed the semantic development of the corresponding verb “réparer” (to repair). It was initially used in a concrete sense to designate the action of restoring what is damaged, out of use, but it quickly extended by metonymy to include the labour and parts required for this operation. The plural form “réparations” took on the particular sense of maintenance or restoration work (from c. 14th century), and was later applied to the action of restoring the part of an object that has suffered damage (since 1690), a meaning that became common in the 20th century in mechanics.

Historically, we can understand the confusion of the two terms. However, from an abstract and general point of view, we can observe that while maintenance works can often be described as repairs, the reverse is not always true. After all, not all repairs are carried out as a part of maintenance. In the archaeological literature, the presentation of the “repair” of damage approaches

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these works from the perspective of the nature of the causes – whether natural or human – of the damage observed. There is a very rich Latin vocabulary for describing operations of repair: "*sarcire, reficere, restituere, aedificare, ponere et celere demolire*" (Lex Quinctia, 9th century B.C., cited by Dessales 2011; Davoine 2019; Ronin and Möller 2019). This author distinguishes between a wide range of natural causes of damage: the action of time (*vetustas*), conceived as a process of which one becomes aware only suddenly, rather than as a progressive action; the action of external elements (*tempestates*), such as wind, humidity, drought, or even all natural disasters (Dessales, forthcoming publication); the fragility of constructions depending on their structural function, such as the role of loads and thrusts; and the specific nature of certain building materials, or the degradation inherent in the use of certain building elements (calcareous concretions in water supply channels, degradation of the internal lining leading to leaks). As for human causes, the author distinguishes between faulty workmanship (unreliable plans, failure to comply with specifications, poor construction, weak foundations, poor choice of materials) and the improper treatment of built structures (either through the inappropriate use of the structure or through direct or indirect fraud), all of which increase the liability of the client, or that of the user of the property. In all these cases, we can use the concept of "repairs" to be carried out in order to make good the observed damages, but can we describe all these processes as "maintenance"?

What about technical literature? In Italy, the two main treatises on architecture that describe the act of building in all its aspects published by Alberti and Scamozzi both devoted an entire book to repairs. Alberti dedicates the tenth book (the last one) of *De re aedificatoria* (1452) to the repair of building works, over 17 chapters. The first chapter proposes, for the first time, a theory of repair (Choay 1980, 129), focusing in particular on the types of defects and their causes, inspired by the Hippocratic treatises, which distinguish between illnesses that are due to faults caused by designers and those caused by nature (Alberti 2004, 467). The faults due to designers result either from the mind (defect of design) or from the hand (defects of realisation). Some defects can be corrected by "art and intelligence", while others cannot. The last two chapters focus on the technical deterioration of the built elements (walls, frames), which crack, collapse, and deform, and for which he proposes remedies including underpinning. In a very rich discussion in chapter 16, Alberti mentions the use among the ancients of teams devoted to the inspection and maintenance of public works, as well as the precautions to be taken in siting private construction projects away from the harmful effects of tree roots.

Scamozzi, in *Dell'idea dell'architettura universale*, published in 1615, had originally planned a treatise consisting of four parts: the *precognitione*, or body of knowledge required by the architect; the *edificatione*, or construction process; the *finimento*, or finishing; and the *restaurazione* or restoration of old buildings (book X) which would never be published.

In France, no architectural treatise of the early modern era grants such a large place to the issue of repairs. This topic is generally dealt with in different chapters, depending on the nature of the operations. Philippe de La Hire (1640–1718), who was a professor at the Academy of Architecture without being an architect, was one of the first to approach the issue of repair in the third part of his unpublished course on architecture, which is devoted to the execution of building work (Becchi et al 2009). While his last chapter is devoted to repairs carried out through underpinning, he specifies that repairs carried out in the water are treated in the section devoted to bridge piles. He also discusses repairs with regard to lead, and it arises in the chapter on walls and vaults, as well as in the chapter on roofs, domes, and coverings.

The same is true in the books devoted to estimating the quality, quantity, and costs of building works ("toisés des bâtiments"), where the issue of repairs is again scattered between different sections. Pierre Bullet addresses the issue of roof repairs in the chapter entitled "Toisé des couvertures" (estimations of coverings) of his *Architecture pratique* (1691, 257), whereas he discusses how to estimate the repair of old walls in the chapter devoted to processes of sealing ("Des scellements") (102). In the middle of the 18th century, repairs became the subject of specific descriptions. In the 1762 edition of *l'Architecture pratique*, an entire chapter is devoted to the repair of holes and wall coatings ("*Des renformis et ravalemens*") (118). François Potain, in his *Détail des ouvrages de menuiserie pour les bâtimens* 1778 (2nd ed.), devotes a chapter to "*Observations sur les changemens & raccommodages d'ouvrages anciens ou changés*" (p. 194). The term "entretien" (maintenance) appears in the case of coverings, where roofers have annual contracts (Le Camus de Mézières 1786; Monroy 1785, 173–177).

A whole technical vocabulary of repair and maintenance was developed for this purpose: it could be found in architectural dictionaries, such as those of D'Aviler (1720) or Quatremère de Quincy (1788), where there is an abundance of terms to designate both defects and repair operations, divided by the relevant trades and materials. Examples of new terms include: "ragréer, regratter" (refinishing), "recueillir, raccorder une reprise" (connecting an underpinned wall to the wall above), "renformir/renformer" (partially rebuilding with new stone), "reprendre en sous-œuvre" (underpinning), etc.

Antoine Desgodets, who was effectively Philippe de La Hire's successor as a professor at the Academy of Architecture, brought about a change in the way architects approached the question of repairs and maintenance. Indeed, in addition to his teaching on "les ordres architecturaux" and "la commodité" (the conventions for the proportions of buildings), he added two new disciplines, which were intended specifically for experts: building law and the "toisé des bâtiments" (the estimation of building works) (Carvais 2013a, 2013b, 2014, forthcoming). On the basis of his general research on the interactions between law and architecture, he constructed his course around two main recurring issues: easements and repair work. Although he was not the first to combine the fields of law and architecture, he was the first to present such a broad vision of the issue by including, among other questions, that of repair work: "[…] this second part explains several other articles of the same Custom, which architects must understand, and most of which can only be explained by people experienced in building. – There will first be discussion all kinds of repairs of tenements that produce annual income, [p. 364] of clerical property, and of churches, addressing the way these repairs are to be made, and by whom. – Then we discuss what part of the things found in buildings are movable or immovable property and several circumstances concerning "retrait lignager" [lineage withdrawal, the preferential right to purchase by reason of consanguinity] that concern the repairs and reconstructions of newly acquired buildings. – Finally, we address the statute of limitations on tenements and work done on them." (Desgodets 1723–1725; Carvais 2020).

The important place occupied by repairs in the Custom of Paris is mainly explained by the issues relating to the sharing of pecuniary responsibilities that may arise in the context of the maintenance of built structures in various legal situations such as co-ownership, rental, and the sharing of obligations between usufruct and bare ownership in the event of changes of ownership.

After his treatise was published posthumously in 1748, under the title *Loix des bastimens*, with the assistance and comments of Martin Goupy, an expert bourgeois architect, it was brought into line with the Civil Code in 1808 by P. Lepage, a former lawyer. It was subsequently updated throughout the 19th century by other jurists (Destrem 1845) or architects (Le Bègue 1874). In these later forms it retained the theme of repairs in its second part, but now approaching it in a much broader sense, corresponding to this description on its new title page: "repairs caused by construction defects, accidents and obsolescence; which includes the warranty of architects, contractors and workers; estimates and contracts; building privilege; fortuitous events; work done at a neighbour's home; fires; leaseholders' repairs, usufructuary repairs and owners' repairs". The idea of liability, which had less importance in the 18th century, took on a more significant place with the cult of the responsible individual established by the Civil Code.

From the 18th century onwards, this legal literature on repairs developed in relation to a specific architectural heritage – that of religious buildings – which was rapidly expanding and, above all, ageing, thereby raising the same initial questions about who was in charge of repairs and what to repair (Pialès 1762; Bordeaux 1852; for the situation in England, see Woods 1809; Elmes 1827 and 1829). The close links between these two notions at the time can be seen from the entries on "entretien" and "réparation" in Quatremère de Quincy's *Dictionnaire* (1788). Moreover, it should be pointed out that the notion of maintenance has only recently constituted a legal category at the theoretical level (Michelin-Brachet 2019). The question of repair and constructive maintenance could be explored in greater depth with reference to the theoretical literature devoted to legal issues (Carvais 2019).

Besides the teaching and theory relating to maintenance and repair, it is also important to look at practices. The question of maintenance occupied a central place in the organization of the King's Buildings, with services dedicated to the task, yet it does not seem to have given rise to printed texts (Idoux 2015). It would later come to occupy a distinct place in the administrative organization of civil buildings and the Direction des travaux de Paris (Chateau-Dutier 2016). The archives of particular building sites or institutions in charge of maintenance are obviously relevant sources for these practices (Bethune 2001). For Paris, its "faubourgs" and suburbs, and even all the territory of the provostry and viscounty of Paris, we have an exceptional stock of archives: that of the constructive work carried out by the dual corps of expert architects combined with bourgeois and expert contractors, which is preserved by the corps of the Greffiers des Bâtiments (Clerks of Buildings) (1690–1790). These assessments of buildings, which were carried out in response to very specific commissions from clients, and which constitute decision-making aids, were sometimes carried out free of charge or on friendly terms, and sometimes as a part of legal proceedings at the request of magistrates. These abundant records give us a fairly reliable picture of the constructive practices of the time. Indeed, this source proves to be fairly representative of contemporary activity in the building sector. These assessments constituted a common procedure, for architectural works ranging from public buildings to a simple hovel. Moreover, our current study only covers a sample of ten non-contiguous years from across the period 1690–1790 (circa 7,000 appraisals), the recurrence of certain elements allows us to provide answers with considerable confidence to the questions raised by the issues of maintenance and repairs during this period.

In the table below, based on the appraisals covering four non-contiguous years, we have counted the appraisals that are concerned principally and directly by repairs. These files are mainly made up of two types of appraisals: those relating to the acceptance and assessment of works that have been completed, and those that describe and assess future works. We have also noted those cases that are only incidentally concerned with repairs, which mainly arise from visits focused on property estimates, partitions, inheritance, transaction settlements, etc., or if they are required as part of a neighbourhood dispute or a disagreement between different owners of dismembered properties. The final category of appraisals, which we describe as "administrative" appraisals, only rarely address the issue of repairs. These include those appraisals that

Table 1. Number of reports concerned with a repair operation.

Year	Reports Nb	Nb with repair/ mentioning a	% repair
1696	471	126/149	26.75/31.63
1726	473	86/141	18.18/29.81
1756	458	117/132	25.54/28.82
1776	728	124/223	17.03/30.63

are required in the context of obligations for the constitution of the contractor's privilege, according to the Parliament's decision of 18 August 1766, or those carried out in connection with non-conflictual alignments (Table 1).

It is clear that the proportion of expert appraisals concerned directly with repairs is quantitatively significant (between 17% and 27%). This indication stabilises at around 30% of all cases if we include appraisals that mention repairs only incidentally. This rate would undoubtedly be higher if we had included all appraisals that use the term "repair". In fact, the appraisals counted here conform to two main cases: either the expert appraisal is in principle anticipatory (it defines the repairs to be made and, if necessary, estimates their cost), or the expert appraisal is verified retrospectively in order to check that the planned repairs have been carried out correctly, when this is deemed necessary.

However, when an appraisal finds faults in a work that has been carried out, this may give rise to a recommendation for repairs (828–17), concerning a defective ceiling). Appraisals may also recommend repairs when addressing the recovery of a building following a fire (828–84). When a party wall is found to be defective or a cesspit is in a poor condition, repairs are always recommended (578–33).

Although the experts very often refer to repairs as being either "principal" or "accessory", they distinguish between construction work (830–34), reconstruction (where nothing is kept from the old construction), changes to the original project, increasing parts of buildings (additions or outbuildings), and repair. The final category relates to the correction of defects caused by human hand (faults or damage), those caused by inaction (lack of maintenance), and those caused by obsolescence (the passage of time, the natural effects of the elements, 581–15).

Based on this exceptional source of Parisian expert reports, we have analysed the notions of repair and maintenance from three different perspectives: technical, economic, and legal.

2 THE TECHNICAL DIMENSION

What damage needed to be repair? And what was not considered worth repairing? With what intellectual and material tools did the experts observe the building? Were they attentive to the material causes of the damage? And what solutions did they propose? The exceptional collection of Parisian expert appraisals makes it possible to grasp the development of knowledge and know-how relating to the repair of buildings.

2.1 *What was worth repairing and what was not?*

We know that the practice of repair was common in the 18th century, but we are nevertheless surprised by the extent of this practice. Everything was potentially subject to repairs. Repairs could be carried out on the entire building, even when it was deemed to be "in ruins" (583–19). Most of the time, however, they were carried out on a specific part: walls, floors, roofs, stairs, windows, cesspools, ovens, wells, pumps, etc. Nevertheless, some defects were regarded as unrepairable. Such was the case for parts that were considered to be too damaged and threatened to collapse. In these cases, the danger that the structure presented for the inhabitants led the experts to recommend that the building be demolished. On 31 July 1726, experts climbed a staircase in such a bad state that one of them considered that he himself was in danger. The report mentions casual repairs which today seem frighteningly inadequate. Simple planks are laid on top of broken and collapsed masonry. The expert writes in his report that all "is in imminent danger of collapse". He considers that "there is not a moment to lose to demolish the staircase completely to prevent the tenants from being buried under the ruins". Although the second expert considered that it could last more than a month with the help of some minor repairs (!), a third expert concluded that its demolition was necessary "to avoid any danger" (582–28).

Demolition could also be considered to be preferable for financial reasons, for example when the cost of repair exceeded the cost of demolition and reconstruction. In July 1726, two experts were commissioned "to decide whether it [was] better to demolish or repair" a house in poor condition. The expert concluded that it would be better to demolish it rather than to go to the expense of "supporting [*étayer*] the wall from top to bottom" before rebuilding it anew (582–24).

2.2 *How did the experts describe the damage?*
What was the basis for their diagnosis?

The reports describe the damage at length and with great precision. Assessments always specify the location of defects and their extent. When a piece of plaster has fallen off, for example, the expert gives the approximate dimensions of the damaged surface. Damaged steps and beams are also carefully counted. The use of drawings, to facilitate the understanding of the damage, is rare.

First of all, the experts' judgement is based on the visible effects of the damage. The appearance of the structures is observed with extreme care. They use a very rich vocabulary to describe changes in the appearance of exterior surfaces. For vertical deformations, specific terms distinguish the deformations according to their shape: walls are “en surplomb” (overhanging), “déversés” (tilting down), “bouclés” (loop-shaped), or “ployés” (bent). In most cases, experts do not attempt to measure deviations precisely with instruments such as a plumb-line, measuring rods (*toise*), a square, or levels. Instruments are only used in specific cases, when the inclination of the wall is such that it compromises the wall’s structural integrity. Pierre Bullet explains in his *Architecture Pratique* (1691) that “the Custom does not give a rule for knowing how far a corrupt wall may overhang before it must be condemned to be demolished, but by convention when it overhangs by a quarter of its thickness, it must be demolished” (Bullet 1691, 326).

Different types of horizontal deformation are also distinguished. Floors, steps, and lintels are “déversés” (tilted), “penchés” (slanted), “affaissé” (slumped), or “hors de leur niveau” (out of level) (1000–62). There are several terms referring to breaks in the surface of walls (“fissures” and “fractions” - cracks and fractures) whose precise meaning we do not understand. A study of this specialized vocabulary would help us to understand the culture of expert.

Experts also rely on changes in the colour and texture of materials. They spot traces of moisture. While sight plays an essential role, visual observation is also complemented by the sense of smell. In 1776, the architect Pierre Taboureur, while examining a faulty pump, observed that a bucket of water that he drew from it “had a bad smell and a yellowish tinge” as if from urine or stagnant water, and was laden with greasy sediment. He deduced that these deposits were slowing down the action of the pump and hindering its operation (1010–31).

2.3 *Did experts pay attention to the causes of the damage? Were the defects at the origins of that damage systematically sought out?*

We have seen that in Book X of *De re aedificatoria*, Alberti formulated a theory of repair based on a distinction between internal and external (or natural) causes. Alberti was not alone in making this distinction. These same two categories of causes were discussed in the 18th century by mathematicians who were called upon by Pope Benedict XIV to pronounce on the damage to the dome of Saint Peter’s in Rome. A causal explanation was central to their expert assessment, to the extent that they paid more attention to the causes of the cracks than to the solutions to these problems. As Pascal Dubourg Glatigny has shown, the causal explanation served to establish the credibility of their expertise (2017, 231).

In contrast, it is useful to examine the role that is given to causes in the reports of practitioners who were called upon to give their opinion on more modest private constructions. In this case, they adopted a much more pragmatic approach. Causes are sought only when this provides useful information for solving the problems at hand. In January 1776, Jacques Denis Antoine and Louis Jules Delespine were asked to give their opinion on the condition of some windows. On first examination, they judged them to be “good and sufficiently solid”, but traces of rainwater on the interior walls forced them to look for the source of the leaks. The discovery of three defects led them to prescribe three separate repairs (999–31).

The ageing process, which Alberti classifies as an external cause of damage in the case of buildings described as “vieux” or “ancien” (old), may be presented as the cause of damage but does not generally call for investigation. A wall judged to be “old” and in a “mauvais état” (poor condition) justifies being rebuilt completely, without further explanation. In March 1776, an expert noted that some chimney flues were “old” and prescribed that they should be repaired to prevent them from falling into the rooms below, or causing a fire (1000–61).

Expert architects and contractors only categorise causes when it is useful for solving the problem at hand. In June 1726, an expert sought to understand whether the repairs to be made were required owing to damage committed by the tenant or by “les injures du temps” (the ravages of time), because he was specifically mandated to do so (581–15). The same applies to defects whose origin is sought in order to determine the responsibility of the builder or to prescribe a repair.

2.4 *What did the repair work consist of?*

The operations related to repairs were extremely diverse. Only a few are described in architectural books: “renformis” (filling holes in the walls), “ravalement” (repairing plaster), “reprise en sous-œuvre” (underpinning), and “remaniement” (repairing roofs). Underpinning was commonly prescribed by building experts, but because it was extremely common, the operation is not explained in detail. In his *Architecture Pratique* (1691) Pierre Bullet describes the way in which roofs were repaired, distinguishing between two types of repairs: “Roofing can be repaired in two ways, one is called rehandling [*remanier à bout*] and the other is called searching [*recherche*]”. The former consists of rebuilding the roof, while the second is limited to finding and changing the damaged tiles (Bullet 1691, 257-8). It is interesting to note that the terms used by Pierre Bullet correspond to those used in the experts’ reports, which confirms the fact that the *toisés* belong to a hybrid genre of writings, as they are based on practices but also aim to regulate, rationalise, and even reform those practices (Nègre 2015).

The reports also describe a series of adjustment and joining operations to connect old structures to new ones, which are absent from architectural treatises and *toisés*. With regard to the repair of fractured or deformed surfaces, the process of levelling gives rise to a series of operations: “dresser” (straightening) and “raboter” (planing).

It is not possible in the space of this article to describe all repair operations. It should be noted that the practice of reuse is omnipresent. All elements are carefully recovered. In 1766, a door damaged in its lower part was removed and disassembled in order to replace the damaged part (899–14). These operations give rise to a series of terms beginning with the suffixes "dé" (*déposé, désassemblé, déscellé, deferré dévitré*, etc.) and "re" (*rétablir, refaire, remanier, reposer, remonter*, etc.).

3 THE ECONOMIC VALUE OF REPAIRS

Experts show a strong propensity to take economic issues into account when dealing with the problem of repairs. In addition, the condition of real estate assets naturally affects the calculation of their value. We therefore find mentions of repairs in the process of making estimations: "the lamentable state of the facades made of strong old timber-framed walls requires rather considerable repairs" (828–86).

Nevertheless, the link between the activity of maintenance and real estate values is far from linear: depending on the type of interventions to which the experts refer, the effects of these operations in terms of estimates can be positive or negative. But economic aspects also play another role in this matter. As well as affecting the price of buildings, repairs are themselves subject to an economic evaluation: on the basis of what criteria, and for what economic purposes, did Parisian experts quantify the cost of the maintenance of buildings?

3.1 *When delaying repairs means losing value*

Both in inheritance proceedings and in the case of sales, "réparations à venir" (future repairs) are often explicitly included by experts among other factors (such as the state of preservation, the size and location of the property, the quality of the building materials...) that have a significant impact on their real estate valuations. Especially when they are qualified as "grosses" (major) and "nécessaires" (necessary), these repairs adversely affect the value of the property: in fact, whenever the cost of these major repairs is specified, it is generally two or three times greater than that of repairs described as "menues" (small). Beyond their costs, the mere reference to the need for major and necessary repairs is often a clear sign of considerable degradation and the poor state of conservation of the buildings, which are two of the main elements that can significantly depreciate their value (Barbot 2015).

In the specific case of estimates made for the purpose of selling a property, however, the reference to future repairs is rarely accompanied by an actual quantification of their cost: in general, these kind of repairs are combined with many other valuation criteria, the sum of which leads to a final value which is usually indicated in an aggregate manner.

3.2 *Enhancing the value of property through maintenance*

Although the principal meaning of the expression "réparations locatives" (rental repairs) is that of interventions that are the tenant's legal and economic responsibility, the same expression may refer to repairs that experts consider to be likely to increase the property's rental value, which is to the direct benefit of the homeowner. In 1696, for example, on the occasion of a visit to a house in rue Villedo (431–12), the expert François Gobin clearly distinguishes between "réparations utiles et nécessaires" (useful and necessary repairs), which will cost the owner a great sum of money, and "réparations locatives et décoratives" (rental and decorative repairs), which are described as being much more advantageous than the former. The expression "decorative repairs" refers to a series of operations whose objective is not to solve a structural problem present in the building, but to enhance its appearance. While the economic advantage of rental repairs lies in the fact that they are paid for entirely by the tenant, decorative interventions are considered to be equally advantageous because, by improving the aesthetics of the house, they directly contribute to increasing its economic value.

3.3 *To rent, sell, or divest? Repairs at the centre of a strategic economic rationality*

In the absence of real estate agents in the modern sense of the term, experts also acted as consultants and intermediaries in the urban real estate market (Barbot 2012), and the evaluation of repairs was, for them, a primary criterion in properly advising owners on the comparative advantages of preserving or disposing of their real estate assets.

If the amount of repairs was too high in relation to the rents paid, experts did not hesitate to recommend that the property be divested. This was the case, for example, of the architect Pierre Taboureur, who was commissioned in February 1776 by Jacques Pierre Dumas to provide a valuation of a house in rue du Faubourg Saint-Antoine, which he had just inherited from his father. After examining the nature, the layout, and the type of buildings and outbuildings of which the property was composed, and after having detailed a large number of repairs, Taboureur concluded his assessment by recommending to Jacques Pierre Dumas that he sell his house "in the state it is in rather than make all the repairs mentioned above" (999–18; but see also 578–79).

4 THE LEGAL REGULATION OF REPAIRS

What are the applicants' motivations: to avoid a disaster by maintaining the building's condition, to economically regulate a legal situation, or to conserve the building in order to increase its value? Because theory is often distorted by practice, it is surprising, to say the least, to find in the archives of expertise, which relate entirely to matters of practice, the same typologies and questions as those that were found in Antoine Desgodets' law course at the Academy with regard to the legal status of repairs. This allows us to confirm that the content of his course was mainly intended for experts. On the one hand, the characteristics of repair operations, such as the variable status of legal subjects in their relationship with the property concerned, establish continuity with the content of the Custom of Paris. On the other hand, however, thanks to the analysis of the expert reports, we uncover two new elements on the nature and potential stakes of repairs.

4.1 *The customary continuities*

These appraisals, which were guided by the terms of the Custom of Paris, use the same distinctive qualities of repairs to determine the distribution of repair charges, depending on the nature of the holders of the property rights and its dismemberments.

Characteristics of repairs: The experts addressed the temporality of the repairs. The repairs may be justified by the urgency of the situation in order to avoid the decline of a house (434–17); or they may even prove to be "very urgent" (828–74). In some cases, they should be carried out without delay in order to avoid danger and ruin (433–8) and to put the property out of danger (579–3). And sometimes they should be supplemented by additional constructions (828–76).

However, we note that the experts distinguish between temporary repairs (repairs to be carried out on the spot both in order to avoid accidents and to ensure the safety of the tenant), very urgent and necessary repairs (to avoid further deterioration of the houses) and repairs that may differ but which are nevertheless necessary for the safety of the house, as well as the safety of the tenants living in the house (828–29).

The properties visited may not be repairable but must instead be completely and urgently rebuilt (578–35). "We believe and our opinion is that it is very urgent and necessary to destroy and pull down the whole house, as it is not possible to restore it and there is no way to live in it in its current state, as it could be ruined and fall down at any moment [in margin: even fire] owing to its poor condition, which is due to both dilapidation and the poor quality of the original construction, and the repairs that have been made to it on different occasions [in margin: not even having been made, for the most part, in a timely manner, solidly, and of good quality], as we have observed. After the said total demolition [in margin: which must be done without delay], while preserving all the parts of the common walls which may be of good quality and sufficient to be used again, the said house must be rebuilt with good quality materials and according to the art, in which reconstruction it may be possible to reuse [in margin: in part] the demolition materials that are good and suitable for reuse" (579–16).

The repairs must prove to be useful, necessary, and indispensable (828–66) in order to make the property functional, "liveable and habitable" (433–6), in short, to be able to rent it out (578–61 *contra* 580–19). Moreover, in cases where the state of the building does not prevent it from being rented, it is not worth incurring significant assessment costs by encumbering the appraisals with details (435–28). Repairs are carried out at the owner's expense to make the house "convenient" for the tenant (433–74). During a period of drought, the use of a functional well can appear to be decisive and legitimise repairs to a house in Place des Victoires (435–6). Following a transfer of nuns to St Mandé and the abandonment of their monastery, experts were called upon to give their opinion on the repairs to be made in order to live in and perform religious service in the cloistered house of the Royal Priory of Notre Dame de La Saussaye, in Villejuif (435–26). For a religious building, residential use is not considered sufficient. It must still be possible to say a mass there. These pragmatic justifications did not prevent the experts from recommending against decorative repairs (431–8). In the case of the non-use of a rented property, responsibility is attributable to the owner and requires either protective measures or repairs (578–13). In addition to these two criteria, there is also the criterion of the uninsured "security" of the public way (580–17).

Sometimes the two characteristics (comfort and profitability) reinforce the usefulness of repairs: "both for the dwelling of the house and to avoid further depreciation" (435–73), or again, "[t]he state of repairs to be made to a house [...] to make it more comfortable, liveable and habitable and, in the event of eviction, the tenant is to be reimbursed for repairs and improvements" (578–30). This surplus value could be recovered if and only if the owner assumed responsibility for the repairs retrospectively.

The final criterion used by the experts is the seriousness of the repairs in terms of importance. Are major or minor repairs required in order to sustain a good level of maintenance (828–60)? The major repairs (for which the appraisal alone took a long time to complete) to be made in the Hôtel d'Alluyes, which was to become the Hôtel d'Angevilliers, are exemplary in this regard (434–8) (435–9, 17, 41 and 59). However, the term "major repair" can be explained above all by the damage caused to the structure of the building, which requires a large intervention (578–32).

The distribution of repair costs according to their nature: the experts were entrusted with determining who should bear the cost of the repairs. This was a recurring question of the interpretation of the Custom of Paris, which was addressed by the literature. It is not a question of attributing responsibility for defects to the person who caused them during the construction process, whether this was a craftsman or an architect. These were sanctioned by the Chamber of the Building Trades during the construction process and by the Châtelet of Paris after the building had been handed over. These disputes could give rise to expert appraisals, but it seems that this only rarely occurred. Expertise was requested for different situations in which repairs were required by one party for a variety of reasons (including damage due to normal weather, extreme weather events, or all fortuitous natural causes). Most of the times, repairs were required because of a failure to carry out appropriate maintenance. So, it is the concept of maintenance defect which then legitimises repairs.

Of course, the owners are the first to be called upon (830–32); the same applies to repairs that are the responsibility of the owner owing to the failure of the "fermier judiciaire" (to whom the lease of a seized property has been attributed by a court) to carry out the required maintenance (830–1). But it is above all when the right of ownership is dismembered, and two types of holder of real rights over the same plot of land are confronted, that the question arises as to which of them will bear the burden of repairs under the conditions specified by the Custom, which distinguishes between the usufructuary (as opposed to the bare owner), the buyer in the viager system the dowager (on her late husband's property), the ecclesiastical benefit (for places of worship) (432–70), and the tenants (830–17). The experts – while it is not their role to interpret the law – are confronted with complex legal issues that force them to understand the application of customary rules. If a tenant fails to maintain the premises, trees, and gardens, he is required to pay for their repair, as he was obliged to do this by his lease (432–47). Who is responsible for paying for the emptying of the cesspit (432–85)? Maintenance repairs are often ordered as a result of tenant negligence (435–14).

Expert reports can also apportion the costs of repairs between the holders of real rights (434–139/following a lineage withdrawal 433–10), or between the landlord and the tenant regarding two pantries (830–47). In the latter case, for example, in order to share the costs of the repairs to be carried out, should the experts take into account the exorbitant price of the rent paid for the disputed premises or should they accept that the tenant enjoyed the use of the premises without complaint? (830–47). In order to make their opinions regarding repairs effective, experts always provided performance guarantees, such as a lien on the rent against the landlord if the landlord were to be responsible for carrying out the repairs (432–33). The judicial "fermier" of a property that has been seized may be authorised to carry out the repairs raised by the expert's report himself and at his own expense, on the condition that he is reimbursed, as a lien against creditors, both out of the money coming or still to come from the judicial lease, and out of the price of the sale in the event of a shortfall (827–9). He could sometimes simply deduct the cost of repairs from the price of his lease (432–54).

Costs could be shared between the landlord and the tenant (579–38). The question of the maintenance of ecclesiastical property gave rise to specific literature (see above) because of the many and frequent conflicts that were raised by the allocation of their financial responsibility, especially after the "revolution" that was imposed in the field of religious architecture by the Council of Trent. We find many expert reports examining this sharing of the burden of repairs, as in the case of the church of St Antoine - St Sulpice in Pin (Seine-et-Marne), where "the choir of the nave and the old enclosure of the complex" (marked in red on the plan and elevation) were maintained at the expense of the clergy (paid for out of their collection of tithes), while everything else, including the new enclosure of the choir (marked in black on the plan and elevation), was maintained at the expense of the inhabitants of the parish (579–41).

Beyond the application of customary provisions, what can we learn from reading the appraisals about the nature and developments of the notions of repair and maintenance?

4.2 *New approaches*

Putting repairs in their general context in relation to other types of works, what control was exercised over them? While the primary aims of restoring property through repairs were functional and economic, did certain expert appraisals reveal a new direction orientated towards a concept of heritage?

Control of repairs: repairs are a type of construction work, and therefore there was no reason for this category to be treated in any other way. From an initial building contract through to its final completion, the same rules of art and technical standards, if any, had to be scrupulously respected.

This is what we find in expert appraisals. Repairs were suggested by the experts, but they had to be listed and costed in order to check that they had been carried out correctly. Drawing up an estimate allowed the parties to evaluate beforehand what they would have to spend. These legal documents are often referred to as appendices to the expert's report, even though they are often no longer to be found there. Frequently, repair verification visits were organized by the experts (carrying out checks and taking an inventory). However, the experts were most involved in the retrospective estimates of the repairs carried out and the control of their implementation according to the rules of the trade (estimation and verification: 828–80). The comparison of the situation on repair sites before and after the work was carried out (the preliminary report was drawn up on the basis of the first visits, which took stock of the situation before recommending remedies) reminds us of the rules to be followed – introduced by the 1766 "arrêt de règlement" (a parliamentary decision with legal force) – governing the granting of contractors' privileges. The same applied to repair works. Moreover, the operation of handing over completed repairs had the same legal consequences as did the handing over of a construction site (829–7). We therefore observe a great attention on the part of the experts to checking the execution of the recommended repairs in person (830–32), which was carried out all the more assiduously if the repairs were carried out in successive waves over several years. For example, Louis Joubert carried out several waves of repair works in the house belonging to Etienne Bouson from 1722 to 1725, amounting to 16,025 livres, for which the expert had to oversee the reception (580–4/Château D'Armentières 581–27). Although the experts "completed" the reception of the repairs, they did not hesitate, if they considered it necessary, to make reservations, such as the installation of a "double iron stirrup which we consider should be put and held in place with an iron bolt" (581–32).

The consideration of architectural heritage: it seems to us that the accumulation of characteristics required for repairs led the experts to envisage another criterion besides improving the practical comfort and/or maintaining the economic value of the property appraised, that of the conservation of the property as a piece of architectural heritage. Although the expert considered the urgency of the intervention, its necessity and practical utility, and its successful execution (through examining both maintenance and structural repairs to the building) one cannot help but think that the indispensable and inescapable nature of the transaction allowed the expert to go beyond the issues of material and economic protection to address that of the maintenance of architectural heritage. This was particularly the case for real estate of a certain importance, and for appraisals that took place in the context of an inheritance (828–68).

From 5 April to 8 May 1756, the expert-architect Jacques-Antoine Payen estimated the urgent and necessary repairs to be made to the Hotel du Cardinal de Richelieu, Place Royale, at a particularly high cost of 78,805 livres, "for its conservation, for fear of a lineage withdrawal of the said hotel, and in order not to be challenged for reimbursement". In other words, in order to preserve an important value that could serve as a guarantee (829–9), beyond the comfort and price of the hotel, the planned repairs constitute an assurance for the owner that his property will persist as part of his fortune.

The "conservation" of a property by means of repairs seems to mean that, beyond maintaining the property in a correct material state and therefore maintaining its economic value, the property is also protected, preserved, and safeguarded as family property, in other words as part of the owner's assets. The expression is frequently used in connection with repairs "necessary for the conservation of the premises at the Courtille, parish of Belleville" (432–38), or for a building and its contents (in this case, fresh, dry, and salted fish from a saltworks, 434–99), or again, "of premises, even making them fit for habitation and able to survive" (435–53). This is all the more evident when one considers that the amount of repairs was substantial, and that everything possible was done to achieve this (579–9). The experts managed to clearly distinguish the purpose(s) of the useful and necessary repairs – which differ from extending parts of the building – "either for the conservation of this house or to facilitate and increase its rental" (999–2).

To conclude, it is imperative to open up a whole research programme, which promises to be rewarding. The practice of repairs and maintenance seems to have developed significantly under the Ancien Régime, although it is still not sufficiently studied. We would, first of all, like to extend our study by means of more complete analyses of expert reports, or possibly through the exploration of other institutional archives that are likely to deal with this issue. Secondly, we would like to develop the study of the repairs and maintenance of public buildings, for which, in the 19th century, a whole organization specialising in this field merged. Indeed, Prosper Mérimée wrote on this subject to Thiers, then Minister of the Interior and Public Works (July 6, 1834): "The bad taste that has presided over most of the repairs made over the last two centuries to our monuments from the Middle Ages has left traces that are perhaps more disastrous than the devastation caused by our civil wars and the Revolution". This was the historical moment that gave rise to the protection of historic monuments and to the "Architectes des bâtiments de France" (public architects devoted to the protection of architectural heritage). Finally, our research programme could open up to a comparison with other European countries.

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To repair, renovate, or replace: A maintenance history of Virginia's state buildings

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ABSTRACT: The life cycles of buildings are subject to the priorities of the individuals who use them, who have authority over them, and who do the practical work of maintaining them. The relationships between these three often become complex and highly negotiated as each attempts to meet its own agenda. This paper uses three case studies from the early 19th century to examine how those entangled relationships impacted the life cycles of the Virginia State Capitol, the Governor's residence, and the Armory. Though built contemporaneously, each underwent different maintenance practices and came to different ends.

1 INTRODUCTION

In December 1810, Virginia Governor John Tyler wrote to the state's legislators regarding the condition of the Governor's residence. "The governor's tenement is fast going to destruction, having been original badly built… The patch-work which has *adorned* it for twenty years has cost greatly more than a good durable brick building would have done" (*Journal of the House of Delegates* 1828). Almost a decade later, Orris Paine, Superintendent of Public Buildings, warned that estimating maintenance costs was an inexact practice, "as it was difficult to say how much, and what would be wanted, as in the case almost always in repairing old buildings" (Paine 1818a). Blair Bolling, a later Superintendent, reported in 1832 that the Armory, which served both as an industrial manufacturing space and as the headquarters for Richmond's Public Guard, was in an uncomfortable condition due to a "perforated" ceiling that exposed the company "to all the cold winds which come from the loft of the building" (Bolling 1832).

Each of these comments captures a moment of negotiation among three interested parties (a user, a craftsman, and an authority) that is eventually materially enacted upon a building. The relationships among these parties therefore shape the evolution of the built environment. Users demand changes to make the spaces more accommodating. Authorities approve the demand. Craftsmen execute it, hopefully in a responsible and workmanlike manner. The building bears it. At the smallest scale, those roles are condensed within a single person, such as a handyman homeowner who improves his house. At the largest, those roles are filed with an ever-changing array of individuals. Such is the case with state-owned buildings that are used by an on-going parade of occupants, under the aegis of changing authorities, and subject to the specialized knowledge of whichever craftsmen submits the lowest bid. Negotiations take on a kaleidoscopic quality at this level, shifting after each election or appointment brings a new person into the on-going conversation. Over the life of a building, this may take place thousands of times. With each new negotiation, the priorities of the three actors may shift. The pattern of those shifts ultimately decide the fate of the building: repair, renovation, or replacement.

In this paper, I attempt to make sense of the decision-making patterns captured in archival maintenance records for three state-owned buildings that entered service contemporaneously in late 18th-century Virginia but that came to dramatically different ends. The Capitol, the Governor's residence, and the Armory began their lives as public buildings in the years immediately following the relocation of Virginia's capital to Richmond in 1780. While the Capitol and the Armory were purpose-built, the Governor's residence was an extant house put to a more formal use. Each suffered similar material failures related to poor initial construction. Despite their similarities, each of these buildings received different kinds and amounts of maintenance and ended their useful lives under different conditions. Today, only one of the three remains standing.

2 METHODOLOGY

2.1 *Sources*

The source materials for this study are found in the Capitol Square Data Records and the Records of the Commandant of the Public Guard at the Library of Virginia. These collections include maintenance reports, official correspondence, receipts, vouchers, executive papers, copies of legislation, and more regarding state-owned buildings, as well as administrative

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paperwork relating to the office of the Superintendent of Public Buildings. The documents produced during the period under consideration here (1800–1840) were produced according to official formulas, but nevertheless contain a wealth of information regarding the buildings under study. The tone of some documents indicates a degree of disillusionment or dissatisfaction with the maintenance regimens enacted on the buildings, while others remain neutral records of costs and materials. Tucked amongst these are letters formally requesting various improvements, which reveal individuals' attempts to adapt their spaces to their own needs, ranging from mere habitability to genuine comfort. Thus, the documents included in these two collections capture not only the physical work done to the buildings, but the varied motivations behind such work.

2.2 *Interpretive Framework and Challenges*

To interpret the documents from these voluminous collections, I rely on two concepts. The first is what Howard Davis described as the culture of building: "the coordinate systems of knowledge, rules, procedures, and habits that surround the building process in a given place and time" (Davis 1999). This approach offers the overarching cultural perspective on the building process, the how and the why of certain choices made over and over again through Virginia's pre-industrial built environment. The second concept is Robert Blair St. George's "maintenance relations" (St. George 1983). Maintenance-related tasks remained important to craftsmen because they ensured the continuity of economic and social relations. In addition, objects made by craftsmen had an implicit proscribed durability, which would drive their owners to seek periodic contractual obligations for repair. Together, these concepts provide a way to balance the physical practices and occupational knowledge inherent to maintaining a building with the social relationships that determined how such work was done.

The ultimate challenge of a project such as this lies in the buildings themselves. The Virginia State Capitol remains in use for its intended purpose; however, much of the physical materials that bore the marks of individual choices in pursuit of a common occupational culture either remain hidden within the walls or have been replaced over time. The Governor's residence and the Armory no longer stand. The lack of material evidence forces reliance on documentary evidence. Therefore, any analysis assumes that the work was executed as proposed.

Nevertheless, while the exact processes of maintenance practices may remain unknown, the documentary archive captured the decision-making processes that informed those practices in sufficient detail that modern scholars can reconstruct them both. In doing so, we can see the patterning that shaped the existences of the Capitol, the Armory, and the Governor's residence.

2.3 *The Actors*

Three types of actors constitute the relationships studied in this paper: the authority, the user, and the maker.

The authority in these cases was played by the executive and legislative branches of Virginia's state government. The Council of State, meant to serve as advisors to the governor, received maintenance requests as often as the governor himself did, held the ability to approve or deny the work as they saw fit, and ultimately disbursed the necessary funds. The Legislature appropriated funds for the construction and maintenance of state-owned buildings and in that capacity were also determiners of the extent to which buildings would be maintained during a given legislative cycle.

The makers were a revolving cadre of men in the building trades. Some undertook only one or two contracts before disappearing from the historical records. Others worked their entire careers in Richmond and left their marks on several buildings. Carpenter Anderson Barret's career spanned five decades and included large contracts on every state-owned building. Similarly, Christopher Tompkins, a sea captain turned builder, oversaw several construction projects between the 1810s and the 1830s. Orris Paine, a brick mason, served as Superintendent of Public Buildings between 1817 and 1818, and has the distinction of being the only craftsman recorded to have constructed and then maintained state buildings.

The users in these cases were temporary occupants of the spaces, there for a gubernatorial term, a legislative session, or a period of enlistment. A few, such as judicial clerks or millwrights, might occupy the spaces for longer periods but still did so without legal claim to the space or to the building. Thus, each user came into a space that was not purpose-built for his occupancy and sought to make it his own so as to ensure his comfort while resident there. This cycle repeated with each new election, appointment, or life change, creating a constant flow of users through these buildings and corresponding constant desires to remake the spaces within them. The most significant among the users was Captain Blair Bolling, Commandant of the Public Guard and Superintendent of Public Edifices. Appointed to the latter role in 1821, Bolling, a former U.S. Army officer and part-time planter, spent the next two decades of his life advocating for the necessary maintenance that these monumental buildings required.

The role of the building must also be considered in these negotiations. Often treated as a mute backdrop to human actions, buildings shape human experiences by directing paths of movement, impacting comfort, creating means access, or providing privacy. In addition, buildings offer a means by which to embody the values of the individual or entity for which they are built. The buildings included in this study embodied both purpose (residence, government meeting space, industrial production) and virtues (Republican families, democracy, self-sufficiency and defense).

In 1783, two years after the state government relocated to Richmond, the Legislature authorized the purchase of a tenement and four lots on Shockoe Hill for use as the governor's residence (*Journal of the House of Delegates* 1828). Though this tenement served as the official governor's house in Richmond for nearly three decades, little documentation survives describing it. Samuel Mordecai, writing in the 1850s, remembered it as: "a very plain wooden building of two stories… for many years unconscious of paint" (Mordecai 1856). John Tyler judged the building he lived in during his father's early 19th century gubernatorial term critically: "The Governor's house… was a building that neither aspired to architectural taste in its construction nor consulted the comfort of its occupants in its interior arrangements" (Tyler 1970). These descriptions portray a building that served as a functional residence and little else. Maintaining even that functionality, however, proved to be a challenge.

During its initial term as the governor's residence, the building received relatively little attention from either the Legislature or the Council of State. The former heard reports on the building and the latter paid the tradesmen who repaired it, but neither body seemed inclined to seriously address the building's consistent material failures for a quarter of a century. Instead, these authorities privileged the construction and maintenance of new, purpose-built buildings that could fully embody the ideals of the state, such as the Capitol that occupied the center of Capitol Square. The governor's residence, by contrast, sat at the northeast corner of the square, seemingly teetering on the edge of the hillside that ran down to Shockoe Creek, and was less readily visible.

The makers who undertook several repair campaigns treated the building circumspectly as well. Unknown hands constructed the building, leaving behind an unworkmanlike structure with which to contend. By December 1800, the Directors of Public Buildings reported it to be nearly derelict. The dwelling house was:

> "greatly injured, not only from natural decay, but also from malconformation in the west end, which is of brick, the foundation of this high wall & in which the chimneys are run is defective… It has settled off from the body of the house… insomuch as to endanger the building greatly, unless it is speedily secured by several large & strong iron clamps… Much injury appears to have been done generally to the foundation by rats" (Directors of Public Buildings 1800).

So low was the quality of the workmanship of the governor's residence that it could be undone by rats. Though repairs were undertaken, within five years "the dwelling house in particular, [was] so conditioned… to be unsafe as a residence," with cracks running through the bricks in one wall, the foundation decaying, and "the chimneys secured by irons bars made fast to the wooden part of the building" (*Journal of the House of Delegates* 1828).

A joint legislative committee at last formed to address the issue in 1806. At the committee's invitation, carpenter Anderson Barret, who had already completed several repairs on the interior of the building, submitted an estimate for the necessary repairs, which included painting the dwelling inside and out, repairing its roof, and laying several brick floors in buildings throughout the property. Barret limited his proposal to largely cosmetic repairs, in line with his previous work in the building, rather than structural ones, even though the new roof would help protect the structural integrity of the dwelling, Barret did not offer to stabilize the foundation or to repoint the chimneys, indicating that he was willing to commit to work he knew he and his workmen could execute well but was comfortable leaving more challenging tasks to someone else. The committee either failed to notice this omission or ignored it, and duly appropriated six hundred dollars for repairs.

Despite Barret's renovations, Governor John Tyler found the residence unacceptable during his occupation. He closed his letter to the House of Delegates in 1810 with the following:

> "The governor's tenement is fast going to destruction, having been original badly built, and it is too small for a family. The patch-work which has *adorned* it for twenty years has cost greatly more than a good durable brick building would have done… The present situation is intolerable for a private family… " (*Journal of the House of Delegates* 1811).

Tyler revealed the physical and familial challenges of living in a government tenement. A house held together by patches and iron bars, with continual foundation failures, not only contributed to a nerve-wracking daily life but made raising a family safely nearly impossible. This new instance on familial well-being also reflected broader societal shifts that privileged the family as the first inculcation of citizenship and virtue (Lewis 1987). If a governor, as the metaphorical father figure of the state, did not live in a sound and true house, he could not raise a family, either literal or metaphorical, of stalwart citizens who would safeguard the independence of the young nation.

The centrality of the family to both society and nation at last brought the Legislature and the Governor into agreement regarding the unsuitability of the extant residence. The building was dismantled in 1811 and the salvageable pieces sold off by Christopher Tompkins, undertaker for the construction of a new state residence. That new residence would be designed by architect Alexander Parris in the fashionable Federal style, balancing republican ideals of private life and public utility in the process, and giving form to Virginia's vision of itself in the early 19th century.

The ultimate fate of the first Governor's residence was determined by the convergence of public interests and private lives among the men in authority and the primary user of the building. When both privileged the family, whether based on immediate personal concerns or on wider societal considerations, the dilapidated condition of the governor's residence was finally addressed, and its fate sealed. The makers, carpenters like Anderson Barret, remained distant from the decision-making process, as they tended to limit their activities on the site to the repairs they could execute well, rather than undertaking repairs that might secure the longevity of the building. The ultimate demise of the governor's residence rested not with the physical failures of the building nor the craftsmen's ability to maintain the structural components but with a shift in the societal expectations of family that resonated with both the Governor and the men in the Legislature.

4 TO REPAIR

Thomas Jefferson designed the Virginia State Capitol to serve two purposes: to manifest classical democratic ideals in the built environment in which the executive, judicial, and legislative members of the government met and worked, and to provide an architectural education for the electorate. While the second purpose never came to fruition, the Capitol continues to fulfill the first, serving as an architectural reminder of the consequence of the work done there. That remainder has remained visible over the course of two centuries because the building has been successfully maintained, which allows its architectural messages to be read clearly. A cache of correspondence written during the tenure of Superintendent of Public Buildings Orris Paine belies the readily accessible nature of the Capitol's messaging and captures the strained negotiations around its maintenance.

Paine proved his competence as a master mason over the course of a three-decade career that included a role in the construction of the Virginia State Penitentiary. Appointed Superintendent of Public Buildings in 1817, he continually clashed with the Council of State regarding how improvements and repairs to the Capitol were to be executed. Paine was accustomed to being a primary authority figure, the status he would have held on work sites as a master craftsman. The Council of State disagreed, favoring their own authority as holders of the purse strings. The Council felt that Paine paid too much for the work done to which Paine responded that some repairs could not be priced until the work was done, "as it was difficult to say how much, and what would be wanted, as in the case almost always in repairing old buildings" (Paine 1818a). The ongoing business of the government occasioned greater expenses as well. The users of the various offices to be repaired could not be relocated en masse, and so the workmen were restrained to completing one room at a time, leaving many of them idle, prolonging the work, and driving up the costs. Paine, as a maker, understood the intertwined flows of the building trades in a way that the Council, as users of the Capitol and as the financial authority, did not. Unsurprisingly, given the tension between Paine and the Council, he forced the executive branch's hand when he could, asking detailed questions regarding exactly what he should do, questions that seem designed to highlight the Council's and the Governor's lack of construction knowledge (Paine 1817).

The Council emphasized their own authority by delaying payments to the contractors and requiring independent verification of accounts. The former had implications at multiple levels as can be seen in appeals to the Council and to the Governor, asking that outstanding accounts be settled after three years (Enos 1819) or documenting a craftsman left destitute from paying their journeymen out of their own pockets while waiting for state disbursements (Gill 1818). When these and other appeals arrived in the Council's chambers, the work was already complete. The Council, as users, already benefitted from the improvements and repairs they had ordered. The Council, as authority, felt the need to exercise utmost fiscal responsibility and would not pay accounts until the work had been verified independently.

The Council's requirement for independent verification brought it and Paine into direct altercation. Paine wrote to Governor James Preston regarding the matter, and the letter lays bare the different priorities of these two parties. Paine confessed he was "some little surprised that the Council should… request of individuals to fix a price to work, and undertake to measure the same without consulting persons concerned" (Paine 1818b). Verifying accounts through independent professional measurement was an established practice in Richmond's building trades and particularly so on state contracts in order to ensure fair pricing and fiscal responsibility. Paine did not take issue with the practice but rather with the apparent fact that the Council solicited these valuations without engaging the men who did the work, who could explain any unexpected challenges that complicated the work and who could recount the repairs hidden behind finished surfaces that might otherwise not be valued at all. This could reduce the wages paid by one-quarter or even one-third, denying the craftsmen their due income and ultimately making them averse to engaging in state contracts. Paine could see no reason why the Council "depart[ed] from the long established custom… of choosing by mutual consent three persons, that the parties might agree upon" (Paine 1818b).

Paine offered an answer to his own question: "Did those members of the Council who advise the procedure recollect that the State was a party interested… ?" (Paine 1818b). The Council in its interactions with Paine and the other craftsmen who repaired and improved the Capitol during these two years seemed to have forgotten that they were an interested party, both as the authority who represented the executive branch of the government and as the body who effectively owned the building. Thus, they could not be impartial, either in their own valuation of the work done or in the selection of evaluators. While in their roles as users, they sought the improvements that Paine and his contractors carried out, in their role as authorities, they refused to acknowledge as equal the role of the makers in maintaining the building. The ultimate arbiter of this conflict, according to Paine: "disinterested men who are considered competent judges should decide on this work" (Paine 1818b).

In the public sphere, when one entity filled the roles of two actors, the process of negotiating and executing repairs failed. With the Council of State filling the roles of both users and authority, they held the power to request and approve improvements to the structure. That dual role also limited their impartiality, as they assessed their own needs, then sought to assign a value to the work others did to meet those needs. In this example, the makers remained active participants, negotiating not for preferred maintenance practices, but for the continuation of accepted practices that safeguarded both the state's coffers and the craftsman's ability to be appropriately compensated for his work. They negotiated not the maintenance practices but the building culture itself. Thus, when one entity fills two of the roles in these maintenance relationships, the building is preserved because doing so ensures that the users remain comfortable in a manner consistent with the authority's priorities. However, the makers may ultimately lose their position in the relationship because they operate at a disadvantage of both real and social capital.

5 TO RENOVATE

The Virginia State Armory was decommissioned in 1821 when a state supply of arms for defense was determined to be unnecessary. Shortly thereafter, the Council of State realized that a large and valuable building would be vacant. To protect the state's investment, they recommended that "a strong detachment as the state of the Public Guard will permit be stationed at the Armory" (Virginia Council of State 1821). Blair Bolling countered the recommendation with his own, that he "remove to the Armory with my company, which is the only means in my power of effectually guarding, at the same the Capitol, Armory, and Penitentiary" (Bolling 1821). In suggesting that the Public Guard be quartered at the Armory, Bolling sought to fulfill his duties as Superintendent of Public Edifices and Commandant of the Public Guard as efficiently as possible. His reports to the Council of State after he relocated, however, painted a bleak picture of a building that barely held together. Small jobs, such as repairs to doors and jambs, replacing glass, and reconfiguring access between floors, made the building habitable within the first few months of its use as the Public Guard's quarters (Bolling 1823a). Thereafter, however, Bolling constantly balanced the comforts of his men against the structural needs of the building and the Council of State's reticence to spend money.

The Armory itself became an active foil to the priorities of its users, makers, and authorities. Structural failures, due to poor workmanship during construction in 1785 and compounded by the constant flow of water through the building's interior millraces, abounded. In 1823, "one of the large girders which supported the joist in one of the trip hammer shops [had] decayed entirely and fallen," leaving the floor to support itself by the planks projecting into the wall (Bolling 1823b). By the end of the year, one floor had "actually tumbled in, which had no weight on it at all and which had not been used for several years in consequence of the decay of the principal girder which supported it" (Bolling 1823c). An examination of the building in 1824 revealed that one corner of the foundation had crumbled and culverts had caved in (Bolling 1824). In January 1828, Bolling discovered "one of the Pillars which support the floor of the west wing of the Armory has given way, and unless it is speedily renewed serious injury may occur" (Bolling 1828). The list of repairs wanted in 1834 included repointing several chimneys, rebuilding caved-in culverts, and replacing sinking floors that endangered living quarters, potentially caused by worms eating through the timbers (Bolling 1834a, 1834b).

Bolling, as the principal representative of the users, relentlessly advocated for the necessary repairs, arguing in each instance a variation on the idea that delay would "lead to serious injury if suffered to continue long in its present state" (Virginia Council of State 1824). Casting the repairs in terms of injuries and lost lives emphasized the importance of the needed repairs. This countered the inertia of the Council of State, which acted as the primary authority. Bolling's requests for funds were often answered by requests to gather estimates and report on the best prices, rather than approvals for expenditures. This insistence on frugality may be due to the fact that the Council of State had little interaction with the Armory, tucked away on the shores of the James River, and therefore did not consider it a priority when compared to the buildings they occupied and interacted with on Capitol Square.

As the Armory slowly became more structurally sound, Bolling turned his attention to the conditions of the guard's quarters, therefore improving the living conditions of his fellow users. Paint, whitewash, and new glass panes were purchased on a regular basis. Ceilings were re-plastered, after the "soldiers handling muskets with fixed bayonets carelessly… perforated the ceiling with holes and… caused the plaster to tumble down" (Bolling 1832). Lewis Chamberlayne, the Guard's surgeon, requested and received "two doors and some additional woodwork… to make the [hospital] apartments as warm and comfortable as the situation of sick men generally calls for," which undoubtedly raised morale among the Public Guard (Chamberlayne 1827).

Repairs to private quarters highlighted the unexpected consequences of turning an industrial space into a comfortable living space and the new negotiations that process required. Repairing the sinking arms storage rooms necessitated the removal of a partition wall that formed part of an Ensign Bentley's quarters below (Bolling 1834c). Bentley requested that the wall be rebuilt in a different location so as to enlarge the space. Bolling agreed, though he warned that any other work would have to come out of Bentley's own pocket. Instead, Bentley petitioned the state to pay the costs of additional improvements. When individuals defined private quarters in state-owned buildings as "personal" spaces, they blurred the line between public and private. This created the possibility of abusing state funds for personal expenses and the subsequent need to reframe negotiations regarding state expenditures for personal comforts.

Absent through this account of the Armory's history have been the craftsmen who worked on the building. Various individuals and firms, including Christopher Tompkins and Anderson Barret, submitted bids and completed work but did not record their thoughts or impressions, even so little as recommendations on various ways to execute the repairs included in their bids. The Armory seemed instead to represent a consistent source of potential income, where the success or failure of a bid going to contract was moot because there would always be another round of bids and more repairs needed.

Following its decommissioning, the Armory was effectively abandoned as an active state building. The residence of the Public Guard ensured sufficient monitoring to avoid catastrophic failures, but the building never received the attention it needed to be returned to its original purpose at a moment's notice. This status as a second-tier state building allowed the men of the Public Guard as users to determine the nature of the building's continued existence, first through Bolling's attention to structural repairs and then through modifications to living spaces designed to increase comfort. The efforts of craftsmen/makers were essential to this process, but they seemed to take little interest in the Armory beyond bidding for and executing contracts. The authority, as represented in the Council of State and the Legislature, took even less interest. As long as Bolling kept costs under control, he had a loose rein to improve the building as he saw fit. Thus, when only one party shows interests in negotiating the maintenance provided to a building, that party's priorities shape the on-going existence of the building.

6 CONCLUSION

The Governor's residence was demolished in 1811 to make way for a fashionable replacement. The west wing of the Armory was lost to a fire in the 1860s, though the east wing stood until it was demolished in 1900. The Capitol remains in use today.

The route that brought these buildings to their various ends was determined by negotiations among the men who used the buildings, the men who held authority over them, and the men who undertook work upon them. The alignment of these parties with or in opposition to one another decided which priorities would be honored in the course of maintaining the building. Users prioritized their safety and comfort. Makers prioritized established practices consistent with the prevailing building culture. Authorities prioritized fiscal responsibility and presentation of state ideals. None of these parties could act independently, however, ensuring that the broader maintenance relationships among them remained intact even when negotiations faltered.

By holding equal the practical processes of maintaining a building and the social relationships that shaped how those processes were implemented, this analysis of the built environment provides a more nuanced understanding of the life cycles of state-owned buildings. Unlike privately owned buildings, where maintenance relations might be a simple transaction of work for compensation, underpinned by the potential of additional future repairs, state-owned buildings were subject to an ever-shifting constellation of makers, users, and authorities. Exploring the tensions among these actors reveals the complex social mechanisms that enabled users to see to the business of government from comfortable quarters, authorities to ensure the continued reputation of the state as a responsible governing entity, and makers to keep the buildings in good repair. Thus, all the actors, despite their often-conflicting priorities, worked together to maintain the state.

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History of Construction Cultures – Mascarenhas-Mateus & Paula Pires (eds)

Conflicts in the Brussels construction sector (1957–59): Judicial expertise of architects, engineers and contractors

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ABSTRACT: The interaction between building professions in 19th- and 20th-century Belgium has mainly been sketched by focusing on the collaborations between the different professionals in day-to-day construction practice or on their professional associations. As a result, a specific form of interaction has not yet received attention: their moments of conflict. Studying legal conflicts and their resolutions offers insights into the ways different professions fought over what should be considered as their competences. Since the 20th century was key to the development of judicial construction expertise by multiple Belgian building actors, this paper analyzes the nature and scope of construction conflicts and their resolution by judicial experts to gain insights into the mutual demarcation of professional competences among architects, engineers and contractors. In order to do so, 48 expert reports on construction conflicts (1957–59) were analyzed, which are preserved in the archive of the Brussels Court of Commerce (State Archives Brussels (SAB)).

1 STUDYING CONFLICTS IN THE CONSTRUCTION SECTOR

Studies on the 19th- and 20th-century professionalization of Belgian architects, engineers and general contractors give insights into the emergence and development of the different building professions: architects focused on design and supervision, engineers on structural analysis and calculations, and general contractors became responsible for organization and execution of construction projects. The increasing complexity of each of their respective tasks resulted in an adaptation of their legal frameworks and protection of the different building professions in the course of the 20th century. These professionalization studies mainly focused on the development of one of these professions. As a result, little is still known about how they interacted in actual construction practice, using their developed professional competences.

This interprofessional context is fundamental to understand the construction sector because professions did not operate in a vacuum and engaged with each other. Within this interprofessional context, they sharpened the mutual division of tasks and solved problems that required expertise from different building professions. Research on this topic has been initiated by studies on the interactions between architects and engineers (Flury 2011; Saint 2007; Weber 2020). Very recently, the relationship with builders and contractors was taken into account as well (Bertels, Dobbels, & Wouters 2017; Bulckaen 2018). These studies focus mainly on the collaborations between the different professionals in day-to-day construction practice or on their professional associations. As a result, one specific form of interaction has not yet been studied: their moments of conflict. These are particularly relevant, because different aspects of interaction and mutual demarcation are concretized in conflict resolution. Studying legal conflict resolutions offers insights into the ways different professions fought over what should be considered as their competences. These conflicts had to be resolved by experts: people who combined knowledge, competences and insights in the domains concerned. Research on such judicial experts is high on the agenda within construction history, but is currently mainly limited to the 19th century (Barbot & Carvais 2020; Friedman 2018; Molteni & Moucheront 2019; Pinto 2018).

Since the 20th century was key to the development of judicial construction expertise by multiple Belgian building actors, this paper analyzes the nature and scope of construction conflicts and the resolution by judicial experts to gain insights into the mutual demarcation of professional competences among architects, engineers and contractors. In order to do so, 48 expert reports on construction conflicts (1957-59), preserved in the archive of the Brussels Court of Commerce (State Archives Brussels (SAB), were analyzed.

First, the different categories of construction conflicts are discussed. Afterwards, different aspects of judicial expertise are analyzed: who was selected as an expert to settle such conflicts? Was there a preeminence of a certain building profession linked to the different legal frameworks? What was the expert’s analysis and assessment based on?

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2 CONSTRUCTION CONFLICTS: CATEGORIES, REASONS AND ACTORS

2.1 *Categories and reasons of conflicts*

The studied reports relate to construction conflicts settled by the Brussels' Court of Commerce (*Tribunal de Commerce, Rechtbank van Koophandel*) in the period 1957-59. This court had jurisdiction in trade matters, i.e. disputes against and between merchants or traders (Muys 1999). Applied to the construction sector, it concerned disputes against and between building actors. Within the 48 cases, four different types of construction conflicts can be distinguished: 1) A first group of 17 cases concerned a construction conflict between the client (*maître d'ouvrage, bouwheer*) and one building actor, e.g. the general contractor, a specialized contractor such as a carpenter or painter, or a real estate agent. 2) A second group of seven projects partly corresponds to this: these are conflicts between the client and multiple building actors such as the architect, general contractor and subcontractors. Together, these two categories comprise half of all cases. 3) Another category of five cases consists of lawsuits initiated by a building actor (e.g. the general contractor or real estate agent) towards the client. 4) Lastly, the largest group of 19 cases are conflicts between different construction actors. In addition to the aforementioned building professions such as (general) contractors, architects and real estate agents, this last category also includes building material manufacturers. (Figure 1)

Within these different categories, construction conflicts were initiated for many different reasons. In the first category, the progress and quality of the construction work carried out was often at the basis of the court case. Were high-quality building materials used? Were the works carried out according to norms and regulations? Were all commitments respected? The financial aspect was also important: in several cases, the cost of the executed works was disputed by the client. The court case was then linked to a survey of the works carried out in order to evaluate the number of working hours charged and quantities of materials and, for instance, to investigate certain material price increases. A number of lawsuits were also filed to assess damages and to obtain advice on the necessary repair works and expected costs.

In the second category (client versus multiple building actors), lawsuits were initiated for similar reasons, such as determining the damage suffered as a result of the installation of a central heating system. But this category also involved more complex problems involving multiple building actors such as architects, (sub)contractors and real estate agents. In such cases, there was disagreement as to who had final responsibility for the construction work if, for example, it had been interrupted by one of the parties.

Within the third category of disputes, initiated by the executing construction companies or real estate agents against clients, the financial aspect was the main factor. These lawsuits resulted from the client's failure to pay (part of) the invoice. This was often linked to disagreements between the various parties about the progress or quality of the construction work, or about an incorrect price calculation.

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Figure 1. Example of the 4th category of construction conflicts. Asphaltco, a contractor specialized in asphalt works, initiated a lawsuit against another contracting company, Dryvinyl. *Annuaire alphabétique belge du Commerce et de l'Industrie. Edition Bruxelloise*. 1958. © City Archive of Brussels (CAB).

Since the fourth category groups conflicts between different construction actors, these lawsuits were often initiated to determine who was responsible for certain defects in a construction project. This involved an analysis of the problem's cause: was the execution (by the contractor or subcontractor) not carried out according to the rules of the art or were bad materials used? Were there any errors in the architect's design plans and/or building specifications?

Or was the engineering office at fault due to mistakes in the technical calculations? Also in these lawsuits, the aim was not only to analyze the situation, but also to find a solution by estimating the necessary repair work and deciding who was to pay for it, at what price and within what period of time. There were also disputes focusing on a particular aspect, e.g. were the architect's fees in proportion to the work carried out? Were the invoiced working hours and quantities of materials in the contractors' invoices, correct?

2.2 *Development of building professions and wider construction sector*

A lot of these construction conflicts thus concentrated on the respective responsibilities, competences and division of tasks between the building actors involved. This gives us insight in the development of the building professions and the wider construction sector in Belgium in the 1950s. In the 48 conflicts, a total of 30 different clients, 62 (general) contractors, six architects, five real estate developers and three building material manufacturers were involved. This largely reflects the classic triangle of actors within the construction sector. Since a construction project required cooperation between the client, the architect and the (general) contractor, most conflicts arose between these three actors. As a lot of conflicts focused on (the lack of) proper execution of construction works, most interaction took place between clients and executing building actors such as general contractors and specialized contractors.

Besides the three classic construction actors, a small number of real estate developers and building material manufacturers were noticeable as well. This is linked to changes in the Belgian construction sector. Real estate development became an important part of construction activity after the Second World War. Real estate companies offered the 'design and built deal', taking responsibility for the whole construction process from design to delivery of the finished construction project. The cost price of the entire project was determined in advance and the client only had one point of contact. Because these practices were only legally embedded in 1971 with the Housing Act or Breyne Act, before that date many conflicts arose linked to the risks of insolvency of the real estate developer (after candidate buyers had already paid an advance), an incorrect project execution or a lack of supervision of the execution, leading to miscalculations and defects (Theunis 2008).

The involvement of building material manufacturers in a number of conflicts points to the wide extent of the construction sector and its actors. Material producers and suppliers indeed play an important role in the functioning of the construction sector, although until now, these construction sectors have only received limited attention within construction history research.

Finally, a building actor who remains out of the picture in the conflicts studied is the engineer. Since the 1930s, engineers have occupied an increasingly important position in the construction process, both in the calculation, design and supervision of infrastructural or civil engineering projects and the material-technical calculations of (mainly large) architectural construction projects. Therefore it is somewhat surprising that engineers were never mentioned as an involved party in the construction conflicts. A possible explanation is the size of the construction projects: engineers were mainly involved in large and public construction projects, while a lot of the conflicts concerned small construction works in which probably no engineer participated. Furthermore, engineers were not mentioned directly as a party in the conflicts, but were perhaps indirectly involved, for instance through contracting firms. Indeed, large contractors did not always work with external engineering offices or consulting engineers, but sometimes hired their own in-house engineers for calculations of among others reinforced concrete and steel projects. As a result, some of the conflicts involving contractors may also have related to the range of tasks and responsibilities of engineers employed in these contracting firms.

3 BACKGROUND OF CONSTRUCTION EXPERTS

In order to settle a construction conflict at the Court of Commerce, the judge appointed an expert. These judicial experts were people who combined knowledge, competences and insights in the domains concerned. For the 48 disputes, a total of 28 different experts were appointed. About half of them were therefore quite active as experts and were selected in different disputes: 15 experts were only involved in one conflict, but the other 13 were appointed multiple times during the studied period, in two to six different construction conflicts (Table 1).

Table 1. Number of times appointed as expert in the construction conflicts settled by the Brussels' Court of Commerce (1957–59).

Number of times appointed	Number of experts
1	15
2	10
3	1
4	1
6	1

3.1 *Professional background*

The selection of experts for resolving construction conflicts mirrors the competences acknowledged to their profession by the court that relies on them (Souris 1994). It is therefore interesting to analyze the professional background of the appointed experts: which building professionals were seen as experts and could act as judicial experts in construction conflicts? Was this linked to their different legal frameworks? In the course of the 20th century, the legal frameworks of the different Belgian building professions were indeed adapted. In 1938, Belgian engineers obtained legal protection and, in 1939, the law on the protection of the profession of architect was designated. The resulting legally disadvantageous position of contractors was only settled in 1964, when their profession was legally protected (Dobbels 2018). Therefore, it could be expected that mainly engineers and architects were appointed as experts in the 1950s, because their professions were already protected by Belgian law.

As can be seen in Table 2, the majority (11/28 experts) were architects. They described their profession as architect (3), architect and property surveyor (6), architect and urban planner (1), or architect, urban planner and property surveyor (1). Architectural experts were appointed in all 4 categories of construction conflicts. In total, they were involved in 21 of the 48 lawsuits. This is not surprising: in Belgium, architects were already recognized as construction experts from the turn of the 20th century onwards. This is indicated by the 1900 issue of the *Annuaire Belge de Bâtiment et des Travaux Publics*. This Belgian yearbook on the construction sector contained a list of names related to different building professions, including 'Experts'. In 1900, the vast majority of judicial experts were architects, sometimes also mentioned as

Table 2. Name and profession of experts, number of times appointed in the construction conflicts settled by the Brussels' Court of Commerce (1957–59).

#.	Name expert	Profession
2.	Aerts Louis	Contractor (roofing)
1.	Andrianne J.L.C.	Engineer
1.	Bogaert Pierre E.	Trader in flooring
2.	Carez Léon	Architect, property surveyor
1	Danthine Armand N.	Company auditor
2.	Declercq-Sole René	Architect, property surveyor
1	Draelants Alphonse	Contractor (painting)
1	Forton Paul	Real estate surveyor
3	Goisse Jules Jts	Contractor (carpentry)
1	Hellinckx Jean	Contractor
2	Heyden Paul	Engineer *(Ingénieur tec.)*, Architect
1	Heyden Fernand	Architect, urban planner
2	Leemans Louis	Architect, property surveyor
1	Menu Alfred	Contractor (painting)
1	Moerman Jean-Felix	Engineer (*Ingénieur civil*)
6	Peeters Auguste	Architect, urban planner, property surveyor
2	Peeters Robert	Contractor (painting)
1	Philippon Louis	Expert
2.	Piquet Robert	Architect, property surveyor
1	Prevot André	Architect, property surveyor
2	Slooven Antoine	Architect, property surveyor
2.	Storrer Albert	Engineer (*Ingénieur civil*), Architect
1	Van de Berg Paul	Architect
2	van Elewyck Georges	Contractor (carpentry)
4.	van Grunderbeek Jos	Judicial real estate expert
1	Van Haelen Victor	Architect
1	Vincent Roger L.	Mediator
1	*Unknown*	Architect

architects-surveyors. At the end of the 1950s they had a less dominant position, but still formed the largest group within the appointed judicial experts (Dobbels 2018).

Although the disputing parties of the construction conflicts did not include any engineers, four engineers were involved as experts in six lawsuits. Their professional background was labelled engineer (1), *ingénieur civil* (1), *ingénieur civil* and architect (1), or *ingénieur technicien* and architect (1). This shows the division between 'engineers' (*ingénieurs civils, burgerlijk ingenieurs*) who worked for the public administration and 'technical engineers' (*ingénieurs techniciens, technisch ingenieur*) working in the industry or in the public administration, but in lower ranks than the *ingénieurs civils*. In 1890, the academic degree of *ingénieur civil* had already been introduced, which offered them a preliminary legal educational framework. In 1938, the title of engineer was protected for the whole profession of engineers, whether they worked for the public administration or in the industry. But there remained a difference between *ingénieurs civils* and *ingénieurs techniciens*. The latter were obliged to add '*technicien*' to their engineering title (Brion 1986). This is, for instance, seen in the expert reports of Paul Heyden (*ingénieur technicien*) (SAB, *Tribunal de Commerce, Rapports d'expertises*, 2622, 2631). Indeed, both *ingénieurs civils* and *ingénieurs techniciens* could act as judicial experts, and their expertise in structural analysis and calculations was used to assess conflicts between clients and contractors (categories 1 and 2) and between building material manufacturers and contractors (category 4).

Furthermore, contractors could also act as judicial experts (7/28 experts). Their professional background was specified as contractor (1), contractor (carpentry) (2), contractor (painting) (3), or contractor (roofing) (1). They were involved in all four categories of construction conflicts, in 12 out of the 48 cases. It is remarkable that contractors, whose profession was not yet legally embedded at that moment, could act as experts in so many cases. This shows that the efforts of the Belgian general contractors' association *Fédération des Entrepreneurs* had an impact. From the end of the 19th century onwards, this Belgian professional association tried to demarcate the profession of (general) contractor in relation to other building actors such as architects and engineers. In 1900, the *Fédération des Entrepreneurs* for instance criticized that the majority of judicial experts were architects-surveyors, while they did not have an encompassing knowledge on all construction aspects (Dobbels 2018). The professional association advocated to expand the group of experts, and to allow contractors to act as experts as well, because they had specific competences on issues such as the organization of the construction site, the use of materials and (mechanized) execution methods. It appeared that, 50 years later, their plea had been answered.

Similar to the observations made for the disputing parties of the construction conflicts, within the group of experts a small number of real estate and building material actors were also noticeable. Pierre E. Bogaert's profession was mentioned as a 'trader in flooring material'. His practical experience with flooring material was requested in a conflict between a client and a contractor specialized in flooring (SAB, *Tribunal de Commerce, Rapports d'expertises*, 2622, 2633). In the 1958 issue of the *Annuaire alphabétique belge du Commerce et de l'Industrie. Edition Bruxelloise*, a precursor of the current Yellow Pages, his profession is mentioned more broadly as 'trader in building materials': *Matériaux de construction, Fournisseur breveté de la Cour, Les Grands Magasins de la Construction (plus de 3000 articles en stock), Tous les plastiques pour le bâtiment, anc. Maison fondée en 1837 (Ets.)* (CAB, Online Almanacs 1958). He probably adjusted his professional background in the expert report, based on the specific expertise required for the conflict.

Given the increasing importance of real estate development and companies, it seems logical that experts specialized in this field came to the fore after the Second World War. Paul Forton described himself as real estate surveyor and Jos Van Grunderbeek, who was appointed in four different conflicts, was mentioned as judicial real estate expert. They were appointed in conflicts between clients and contractors, a client versus a real estate developer, and lawsuits between contractors (SAB, *Tribunal de Commerce, Rapports d'expertises*, 2622, 2623, 2627, 2629, 2634). It is unclear what their specific professional background was: were they architects, engineers, contractors, surveyors specialized in assessing real estate developments? The *Annuaire alphabétique belge du Commerce et de l'Industrie* does not offer any additional information. Neither Paul Forton nor Jos Van Grunderbeek are mentioned in the 1958 or 1960 issues (CAB, Online Almanacs).

Besides these different construction experts, three more general experts were also appointed in three lawsuits studied. The backgrounds of these experts remain rather vague as they were described as company auditor (Armand Nicolas Danthine), expert (Louis Philippon) and mediator (Roger L. Vincent).

3.2 *Link with professional associations*

When discussing some experts' backgrounds as contractors, the professional association of contractors was already mentioned. The *Fédération des Entrepreneurs*, established in 1881, indeed played an important role in the demarcation of the profession. This association - which was called the *Fédération Nationale Belge du Bâtiment et Travaux Publics* from 1950 onwards - selected and drafted lists of contractors with different specializations, who were proposed to different courts to be appointed in construction conflicts. None of the experts with a professional background in contracting declared a link with this organization. Two contractors specialized in painting (Alfred Menu and Robert Peeters) did mention their membership of the *Chambre syndicale des entrepreneurs de peinture*, which was part of the overarching association of contractors (SAB, *Tribunal de Commerce, Rapports d'expertises*, 2624, 2626).

Another professional association that was explicitly mentioned in the studied lawsuits, is the *Union des Géomètres-Experts de Bruxelles* (UGEB). The experts Louis Leemans and André Prevot mentioned their background as property surveyor and members of the UGEB. They were both described as architects and property surveyors, and also mentioned their membership of the national architects' association *Société Centrale d'Architecture de Belgique* (SCAB) (SAB, *Tribunal de Commerce, Rapports d'expertises*, 2626, 2632, 2634). (Figure 2) These professional associations of surveyors and architects played an important role in the professional organization and demarcation of these building professions.

Auguste PEETERS

En cause de : J. HERREMANS.

Contre : D. VAN BOVEN.

RAPPORT D'EXPERTISE

Figure 2. Judicial expert Auguste Peeters mentions his professional background as architect and membership of the *Société Centrale d'Architecture de Belgique* in the construction conflict Herremans-Van Boven. *Tribunal de Commerce. Rapports d'expertises*, 2630. © State Archives Brussels.

Further research has to show whether they all actively proposed some of their members as possible experts in construction-related lawsuits, and if so, if the proposed experts were actually selected for expert analyses in different courts. Their practices can be compared to the 18th-century Paris construction sector, where professional associations were able to put forward judicial experts from within their association (Carvais 2001). Furthermore, additional research can point out if professional associations of architects, engineers, contractors, surveyors, material traders, real estate developers etc. were able to act as judicial experts themselves, as was the case in the 19th-century Paris construction sector (Lemercier 2003).

4 EXPERT PROCEDURE: BUILDING AND TRANSFER OF KNOWLEDGE

Now that the backgrounds of the disputing parties and experts have been sketched, the expert procedure itself will be briefly outlined. In the studied conflicts, the experts followed a number of reoccurring steps to analyze the construction conflict. Once the expert was appointed by the Court of Commerce, a first step in his assessment was inviting the different parties to a meeting, together with their legal councilors and (if this was the case) with their *conseil technique*. This allowed the parties to tell their side of the story. The judicial expert asked additional questions to get a clearer picture of the situation. It is important that it was the expert's intention to reconcile the parties. Indeed, when an expert was appointed, his duty was described as follows: "*de s'entourant de tous renseignements et documents qui devront être mis à sa disposition par les parties, entendra celles-ci en les conciliera si faire se peut, sinon…* " (to obtain all information and documents which will be made available to him by the parties, to hear them and to reconcile them if possible, otherwise…) SAB, *Tribunal de Commerce, Rapports d'expertises*, 2631).

The expert then studied the project documentation (supplied by the different parties) such as building specifications, design plans and submitted bids in order to determine what was included in the construction work. In addition, correspondence between the parties was examined, among others to reconstruct the steps taken by the various building actors. For example, did the architect supervise the works correctly? Did he indicate (in writing) which mistakes a contractor had made? On which dates were which construction works carried out?

This was combined with at least one site visit to *les lieux litigeux* with all parties and their representatives, to analyze the problems on site, to determine which construction works had not been carried out (qualitatively), etc.

Subsequently, at least one meeting took place in the Brussels courthouse between the judicial expert and the councilors and/or *conseils techniques* of the disputing parties. The *conseils techniques* were additional construction experts, hired by the different parties to represent their interests. It is logical that they mainly chose people with a professional background and expertise in their own field. Architects, for example, primarily chose an architect as *conseil technique*, whereas contractors had a more practice-oriented approach and rather called on contractors, building material producers and suppliers, or site supervisors. Once these experts had reached an agreement, this was submitted to the disputing parties. If they agreed, the judicial expert drew the report.

There were certain guidelines for writing such an expert report. In 1935, for example, the contractors' association already mentioned a model report for assessing construction-related disputes (Archive FEGC, *Bondsblad*, 1/1/1935). To date, however, no such model reports have been retrieved. The 48 expert reports did all have a similar layout. They start with a clear overview page, listing the cause of conflict, the different parties involved (name, profession / company) and information about the expert who wrote the report (name, profession, background). (Figure 3) Afterwards, the expert describes his process of assessment, sometimes accompanied by photographs of the *lieux litigeux*, and gives a clear answer to the predefined research questions. (Figure 4) It is currently unclear who wrote such (legal or factual) guidelines for expert assessment: specialized lawyers, professionals from the construction sector, professional associations of different building professions, professional associations of judicial experts? The *Association Belge des Experts* (ABEX) is such a professional association of experts, established in 1933. Did ABEX publish guidelines for expert assessments by (construction) experts? The ABEX logo is, for instance, displayed on a number of studied expert reports. Judicial construction experts may have also based their work on publications such as *Le guide de l'arbitre à l'usage des architectes, ingénieurs, experts, entrepreneurs, etc. Traité pratique appuyé sur la jurisprudence* (Franck 1928). Such publications were not only important for

Bovendien zijn de verticale voegen niet in een zelfde lijn.

Het dikte der voegen van het gevelparement is zeer onregelmatig.

(25) 69.- De ligger vormende drempel van de ingangsdeur en van garagedeur, is samengesteld uit drie elementen, maar volgens ons, ware het beter hem in een stuk te uitvoeren: Een baksteen vormt voeg tussen de verschillende elementen.

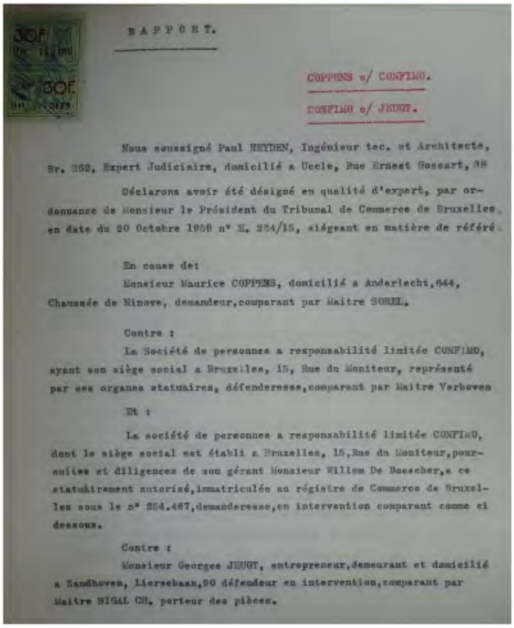
(27) 70.- De linker uiteinde van de drempel van W.C. venster is vertikaal gebroken tegen de lijst naar nr. 79.

71.- In het bovenste gedeelte van de gevel, noteren we dat voeglatten niet weggenomen werden.

Nota.

72.- De garage is belemmerd met verschillende en allerlei materialen.

Figure 3. Example of front page of an expert report, giving information on the disputing parties and judicial expert. Tribunal de Commerce. Rapports d'expertises, 2631. © State Archives Brussels.



RAPPORT.

COPPENS c/ CONFIMO.

CONFIMO c/ JEUGT.

Nous soussigné Paul HEYDEN, Ingénieur tec. et Architecte, Br. 362, Expert Judiciaire, domicilié a Uccle, Rue Ernest Gossart, 38

Déclarons avoir été désigné en qualité d'expert, par ordonnance de Monsieur le Président du Tribunal de Commerce de Bruxelles en date du 20 Octobre 1959 n° E. 254/15, siégeant en matière de référé.

En cause de:

Monsieur Maurice COPPENS, domicilié a Anderlecht, 644, Chaussée de Ninove, demandeur, comparant par Maître SOREL.

Contre :

La Société de personnes a responsabilité limitée CONFIMO, ayant son siège social a Bruxelles, 15, Rue du Moniteur, représenté par ses organes statuaires, défenderesse, comparant par Maître Verbeven

Et :

La société de personnes a responsabilité limitée CONFIMO, dont le siège social est établi a Bruxelles, 15, Rue du Moniteur, poursuites et diligences de son gérant Monsieur Willem De Busscher, a ce statutairement autorisé, immatriculée au régistre de Commerce de Bruxelles sous le n° 254.467, demanderesse, en intervention comparant comme ci dessous.

Contre :

Monsieur Georges JEUGT, entrepreneur, demeurant et domicilié a Zandhoven, Lierseban, 90 défendeur en intervention, comparant par Maître SIGAL CH., porteur des pièces.

Figure 4. Expert report including photographs taken during the site visit to support the expert's analys. Tribunal de Commerce. Rapports d'expertises, 2630 © State Archives Brussels.

the build-up of knowledge (giving examples based on actual construction conflicts) but also for the transfer of this knowledge via a broader diffusion of expert knowledge on the subject.

5 CONCLUSIONS

This analysis of 48 expert reports related to construction conflicts settled by the Brussels' Court of Commerce (1957-59) has given first insights into the construction conflicts, the professional backgrounds of experts and their expert procedure. With regard to the conflicts, the different categories, reasons for lawsuits and disputing parties have been sketched. This sketches a more nuanced picture of the Belgian construction sector in the 1950s, with, for instance, increasing attention to real estate development and building material producers as important actors.

Furthermore, it became clear that actors with a lot of different professional backgrounds could act as an expert in the 1950s Court of Commerce. Because the expert reports are preserved 'an sich', and do not form part of a broader judicial archival file, it is currently still unclear why a particular expert was selected for a particular expertise. It did become clear that both professional experience and previous judicial expertise experience played a role, as half of the experts were at least involved twice in assessing a construction conflict in the studied time period.

A similar observation can be made on the expert procedure. The analysis provided first insights into the different assessment steps undertaken by the expert, and in his writing of an expert report. Further research is needed to gain more in-depth knowledge on, among other things, the published guidelines for expert reports. Expanding the studied period and geographical area will furthermore allow placing these insights into a broader perspective.

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Thematic session: Historical timber constructions between regional tradition and supra-regional influences

History of Construction Cultures – Mascarenhas-Mateus & Paula Pires (eds)

Timber floors made with elements shorter than the span covered in treatises and technical literature

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ABSTRACT: The idea that the maximum dimensions attributable to a space to be covered with a wooden floor are given by the maximum length of the beams available is intuitive, but at the same time limiting. Some of the first examples of attempts to overcome this limit are in Villard de Honnecourt's notebook and on a page of the *Codex Madrid I* by Leonardo da Vinci, testifying that these ideas had been circulating in various parts of Europe amongst wandering builders for a long time. Only with the end of the 18th century did manuals begin to report more precise information on the construction of floors. Despite the large space dedicated to them in handbooks, almost all the authors advised against these techniques, considered unsafe because they entrusted all the resistance to carpentry joints; consequently, the space allowed in the handbooks did not correspond to a similar diffusion in construction practice.

1 INTRODUCTION

The idea that the maximum dimensions attributable to an environment to be covered with a wooden floor are given by the maximum dimensions of the beams available is intuitive, but at the same time limiting. These limits relate both to the length of the beams – the aspect covered in this article – and to their transverse dimensions.

Beginning at least in the Middle Ages, many expedients were developed to overcome the limitations imposed by the dimensions of timber elements.

Single or multiple corbels made of wood or of stone, and wall plates supported by corbels were often used to reduce the free span of beams and joists of timber floors, thus allowing the use of slightly shorter and/or smaller timber elements.

In the north east of Italy, timber composite girders were designed assembling elements obtained from different logs, thus a space could be covered using timber from smaller logs than what would otherwise have been necessary. The composite beam was probably invented in the Middle Ages: examples dating back to the end of the 14th century are known, but it is assumed that the technique dates back at least to the previous century (Badalini & Dandria 2009). Leonardo da Vinci gave a representation of it in a drawing now preserved in the *Codex Atlanticus* (folio 139 recto) and Francesco di Giorgio Martini used it in his manuscripts, Leon Battista Alberti (1546) cited it in his treaty, but without giving a detailed description.

Later de Philibert L'Orme (1561) invented a technique to build arches composed of short timber boards, which he proposed for the construction both of roofs and the main structure of floors.

Rarer are the cases in which a floor was built using only beams shorter than the span to be covered. This paper will focus on their dissemination and the critical reception, or rejection, of this technical solution in treatises and manuals from the 16th to 19th centuries.

2 FIRST REFERENCES TO FLOORS MADE WITH BEAMS SHORTER THAN THE SPAN TO BE COVERED

2.1 *Villard de Honnecourt's sketchbook*

The oldest known drawing of a floor built with beams shorter than the span to be covered is probably the one in the folio 23 recto (Figure 1) of Villard (or Wilars) de Honnecourt's sketchbook (*Livre de portraiture*). This manuscript was owned by the Félibien family before entering the collection of the Abbey of Saint-Germain-des-Prés in the first half of the 18th century, from where in 1795 it was transferred to the *Bibliothèque nationale* in Paris (manuscript n. 19093 of the French fond) (Omont 1906). The manuscript was long ignored until attention was brought to it by Jules Quicherat (1849). He dated it to the fourth decade of the 13th century, while a more recent study places Villard's activity during the first third (Bechmann 2000) or quarter (Wirth 2015) of the century. Later Jean-Baptiste Lassus edited the complete reproduction, which was published after his death by Alfred Darcel in 1858 (Darcel & Lassus 1858), giving rise to an uninterrupted critical fortune of the manuscript. However, all the older studies (Darcel & Lassus 1858; Quicherat 1849; Viollet le Duc 1863; Willis 1859) gave little attention to the drawing of this floor because – as

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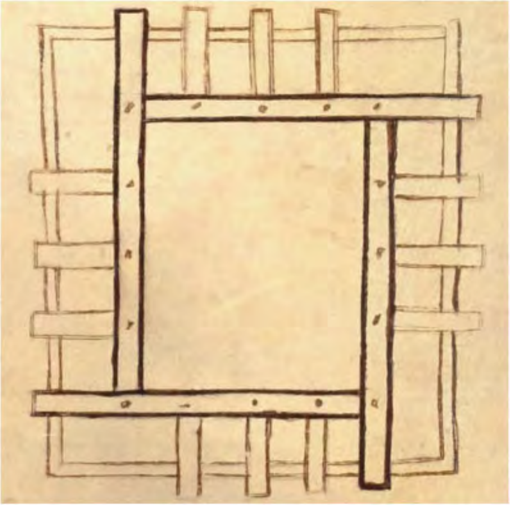

Figure 1. Drawing by Villard de Honnecourt of a floor built with beams shorter than the span to be covered. In the caption, Villard writes “*Ensi poes ovrer a one tor u a one maison de bas si sunt trop cor*”, translated as “So you can use some timber in a tower or in a house if they are too short”.

Willis (1859) affirms – in the 19th century this was already “a well-known system”, “familiar” to architects, since it was published by Serlio (1545) in his treatise in the 16th century.

Villard’s drawing (Figure 1) depicts a floor for a square room, in which four main beams are placed parallel to the walls, arranged so that each has one end resting on a wall and the second upon one of the other beams. The rectangular spaces between each beam and the parallel wall are covered with shorter beams, while nothing is drawn in the central square field. In the caption, Villard proposes the use of this technical solution in towers or rooms. Considering the proportions between the central square field and the bands placed on the perimeter, the technique depicted in the figure seems more appropriate to a tower in the middle of which there is an empty space. Based on his translation of the caption (“how to work on a house or tower even if the timbers are too short”) and considering that the drawing is on the same page as some construction machinery, David Yeomans (1997) supposes that this type of structure “was used just as a temporary structure, a form of scaffolding to work from rather than as a permanent floor structure”.

2.2 *The Codex Madrid I by Leonardo da Vinci*

Other early representations of floors built with beams shorter than the span to be covered are in a drawing by Leonardo da Vinci, in folio 49 verso of the so-called *Codex Madrid I* (manuscript n. 8937) of the *Biblioteca Nacional de España* in Madrid, also known with the Spanish title *Tratado de estatica y mechanica*. On this page of the codex there are two different technical solutions for the same problem.

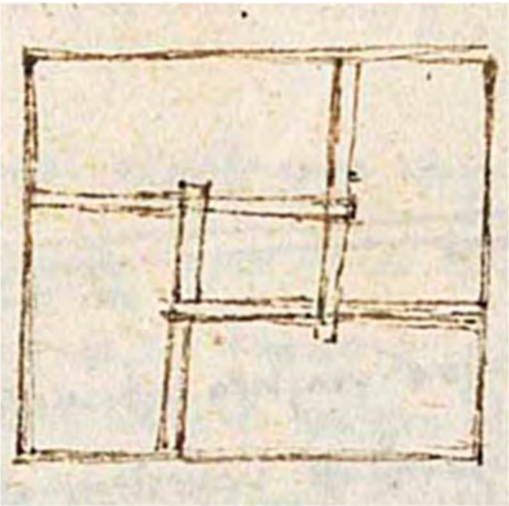

Figure 2. First drawing of a floor built with short beams by Leonardo da Vinci from the *Codex Madrid I*. The drawing has no caption and is placed on the right of the other presented in Figure 3. Since Leonardo used to write from right to left, this should be considered preceding the other.

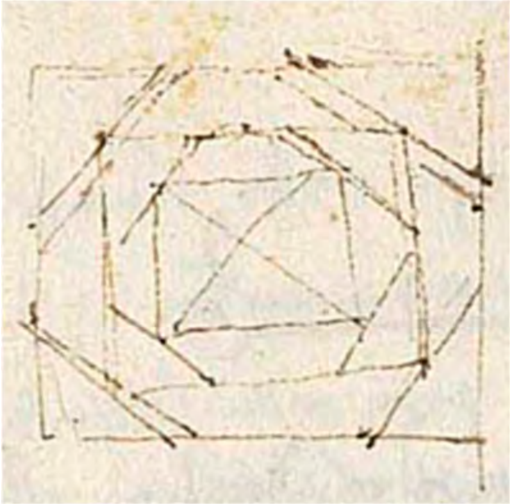

Figure 3. Second drawing by Leonardo da Vinci from the *Codex Madrid I* representing a floor built with short beams.

The first (Figure 2) is better drawn and is similar to that depicted by Villard. There are two main differences, however, between Villard’s and Leonardo’s drawings. The first is that in Villard’s illustration the joints between the beams seem to be tenon-mortice joints with a dowel, while it appears that Leonardo represents the use lap joints. The second is the width of the internal square area: in Villard’s drawing the space is quite wide, while in Leonardo’s the central square side is about one third of the side of the room. In this way each beam is loaded at its center by one of the other.

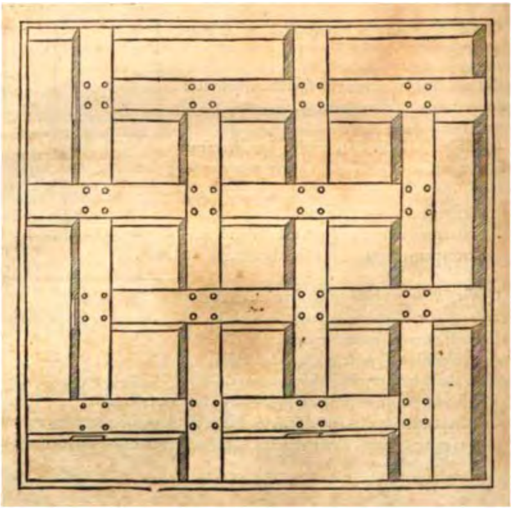

Figure 4. Drawing by Serlio (1545) of a floor with short beams.

The second drawing is only a sketch (Figure 3) and represents a different technical solution that can be used to cover a room with short beams.

In this solution there are many layers of beams: the main beams are placed diagonally, so as to cut the corners of the room, with both ends resting on the walls; the secondary beams rest in the middle of them and define a square space that is homothetic to the walls of the room; inside this square space other diagonal beams are placed and then other parallel beams.

In folio 899 verso of the *Codex Atlanticus*, Leonardo depicts a structure similar – but more complex – to that of the first drawing. In fact, it is a vast structure made by the iteration of the same elementary module. However, reading the caption (a complete transcription is in Williams 2008) it seems that this structure was meant to be a temporary roof covered with fabric, in which the timber elements are simply superimposed on each other and the joints made with ropes.

3 “IL PRIMO LIBRO DI ARCHITETTURA” BY SEBASTIANO SERLIO

The first publication that deals with floors built with short beams dates back to 1545; *Il primo libro d’Architettura* published in Paris by Sebastiano Serlio with both Italian and French text. In this volume – dedicated to geometry – the Italian architect shows a timber floor (Figure 4) obtained by the iteration of the elementary module shown in the drawing by Villard and Leonardo. However, the text seems to allude to a more elementary structure, of which Serlio writes that this “work will be very strong, placing a joist in the wall on one side, and the other end suspended”. He therefore describes a simpler floor, in which each beam has the first end in the wall, and the other resting upon another beam. In the drawing we can see that the beams are connected with lap joints reinforced with four dowels each. From the form of the joint we understand that the floor is depicted from below. In the second edition of the book (Serlio 1551) – published in Italian only – the figure was mirrored.

This drawing was reproduced almost as it is in two treatises published a few years later: the work on architecture printed by the eclectic German writer Ryff (1547) – who owes much to the works of Serlio and other Italian authors – and the second edition of the Italian translation of *De Architectura* by Vitruvius, edited by Daniele Barbaro in 1567 with drawings by Palladio. If in the first the reproduction is faithful, in the second there is the significant difference that the head of the overlapping beams is not shown on the side of the overlapped one.

After these first reproductions, for a long time little interest was devoted to this technique in other treatises, however the circulation of Serlio’s work, in its Italian or French versions or in its various translations, helped spread the knowledge of this kind of floor, that then became linked with the name Serlio.

4 INTEREST IN THE SERLIO FLOOR BETWEEN 17TH AND 18TH CENTURIES

In the 17th century, interest in the Serlio floor was mainly concentrated in England, where the matematician John Wallis was the first to try analyzing this kind of construction from the structural point of view.

Wallis (1670) affirms that he started his studies in 1644, while a *Cantabrigia Collegio Reginensi Socius* (fellow of the Queen’s College in Cambridge), and not long after he curated the construction of a model whose width was four times the length of the longer beams. After he had been appointed to the Savilian Chair of geometry at Oxford in 1649 (O’Connor & Robertson 2002) he gave a lecture in 1652 showing the model and another in 1653 explaining his calculations. These he exposed in Proposition 10 of his Latin treatise *Mechanica: sive, de motu* (a more detailed narration by Wallis himself can be found in Wren 1707). The subject of his proposition was how to “Construct a floor with beams much shorter than the width of the area, joined to each other: and estimate with the calculation how much load falls on each joint”.

The structure he studied (Figure 5) is similar to that depicted in Serlio’s treatise, however there are two fundamental differences. The first is that Wallis uses dovetail joints instead of lap joints; the second is that while in Serlio’s drawing the elementary module is iterated identical to itself, Wallis alternates clockwise and counterclockwise modules. This choice is justified by Wallis who affirms that in this way there is no beam in which it is necessary to make the dovetail notches on the two sides of the beam at the same point, thus substantially reducing the height of the beam by half.

The work by Wallis was written in Latin, and therefore could be accessed outside England. However, even before it was published, news of Wallis’s study of short

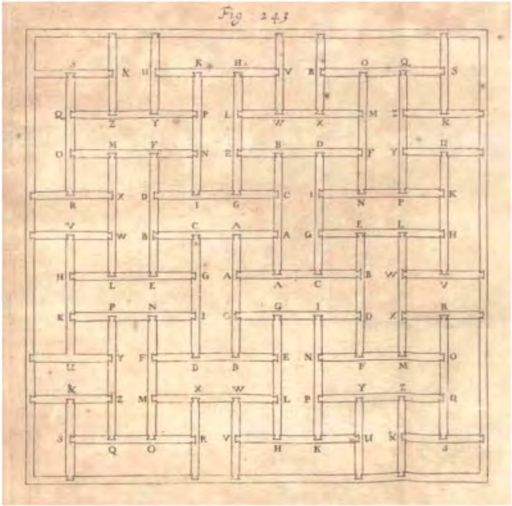

Figure 5. Drawing by Wallis (1670) of a floor with short beams. Alternating clockwise and counter-clockwise modules, the surface of the floor is subdivided into square and rectangular areas, and the beams on the perimeter are shorter than those of the internal parts of the floor.

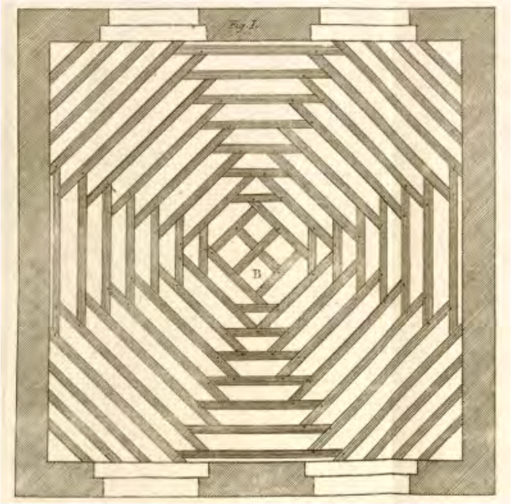

Figure 6. Floor with short beams by Fourneau (1770).

beam floors had reached France through the report of Samuel Sorbière's trip to England published in 1664. Between scientific and social news, this report contained a summarised description of the floor and a drawing almost identical to that in the volume by Wallis. This travel report was also published in Italian (Du Loir & Sorbière 1670) – in which, however, the table was not included – and subsequently translated into English (Sorbière 1707).

Gargiani (2012) cites a drawing in the French edition of *De architectura* by Vitruvius edited by Claude Perrault (1673) as an example of a floor built with short beams. Since the drawing (in footnote 2 at page 314) depicts a timber tower with many similar details, Gargiani hypothesized that Perrault could have known of the drawing by Villard; however, there are more differences than similarities: in the drawing by Perrault, in the empty space in the middle of the floor there is not only a spiral staircase but also a series of vertical supports, that completely changes the behaviour of the structure. Therefore, this drawing could not be considered an example of a floor with short beams, which requires the absence of intermediate supports.

Frézier (1738) considers from a theoretical point of view the Serlio floor: showing a drawing of its primary element. Frézier (1738) affirms that there is no doubt that it had been an inspiration for the so-called flat vaults invented by Joseph Abeille in 1699, and cites the analytical work by Wallis. Frézier also affirms that "invention of this vault [is] more ingenious than the carpentry", but "that this invention is more ingenious than useful", since if only one element fails all the vault/floor will collapse.

Le Camus de Mézières (1782) seems only aware of the floor by Wallis, through its description and drawing are present in the report by Sorbière (1664). Therefore, the only idea he draws from it is related to the convenience of connecting the joists to the beams with a dovetail joint, rather than with the tenon and mortise joint, then usual in France.

In Italy throughout the 17th and 18th centuries the theme of wooden floors is neglected. This aspect is connected on the one hand to the fact that they were losing relevance, due to the progressive diffusion of the vaults, and on the other hand because the construction of the floors was generally entrusted directly to the master carpenter (Del Rosso 1789). The architect was called on only for the design of particularly elaborate decorative elements (Capra 1673).

5 APPLICATIONS OF SHORT BEAM FLOORS BETWEEN THE END OF THE 18TH AND THE BEGINNING OF THE 19TH CENTURIES

Between the end of the 18th and the beginning of the 19th centuries, the treatises and handbooks of architecture and carpentry start to address the theme of floors, also proposing new types of framing.

L'art du trait de charpenterie by Fourneau (1770) is one of the most relevant works of this period and a fundamental reference for subsequent authors. The author shows a timber floor which he claims to have built himself in 1764. This floor (Figure 6) has no principal beams and only uses joists arranged so as to form a series of concentrical octagons. Using only joists, the thickness of the floor was smaller than usual in a room 17x18 French feet wide (i.e. between ca. 550 and 585cm), the floor was only 3x4 French inches thick (i.e. between 8 and 11cm). The ratio between the thickness of the floor and the span was therefore circa 1/72x1/51, that is between 1/2 and 1/3 of the ordinary thickness, according to Rondelet (1810) equal to 1/24 of the span.

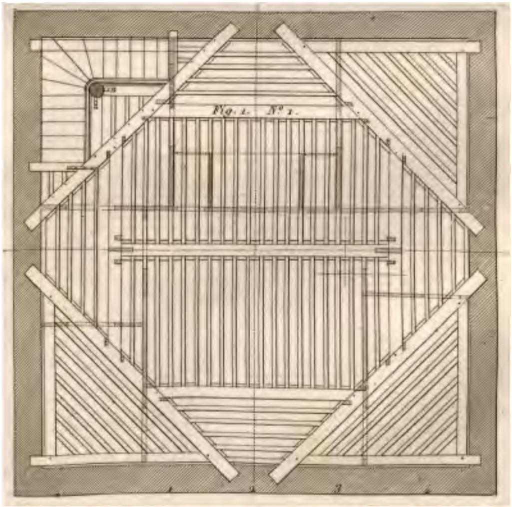

Figure 7. Drawing of a floor with short beams (Krafft 1805).

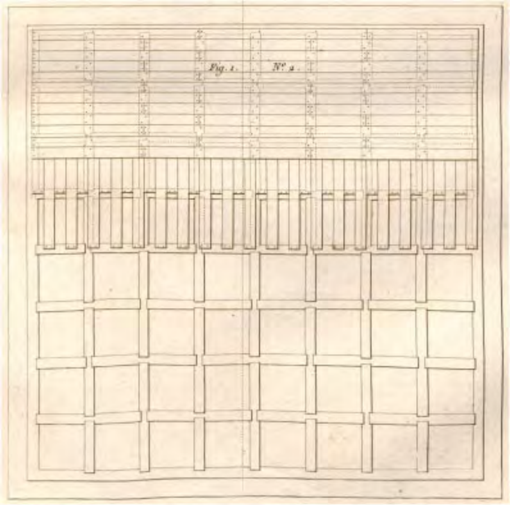

Figure 8. Serlio floor in the Dutch stadhouder's pleasure castle (Krafft 1805).

Fourneau (1770) also affirms that "this method of flooring is suitable for keeping the distances between the walls and resisting the forces of the winds, because each joist readily serves as a strut".

Another milestone in carpentry studies are the books by Jean-Charles (Johann Karl) Krafft, an architect born in Austria and naturalized French. His first volume – *Plans, coupes et élévations de diverses productions de l'art de la charpente* – published in 1805 presents a series of floors actually built with beams shorter than the span to be covered both in France and in the Netherlands.

Two floors – shown in the two halves of the same drawing – are similar to that shown by Fourneau and are appreciated "because there can be used even the smallest piece of timber". Both were built in Paris, the first was designed by the architects Molinos and Legrand for the *Halle aux Draps*, the second by Brongniart in the *Maison Nationale des Militaires Invalides*.

Three other floors are designed with diagonal beams according to a scheme similar that depicted in the second drawing in the *Codex Madrid I* by Leonardo (Figure 3). Two are built in France (one of them in rue Saint-Denis in Paris), the third in the Netherlands; while the two French examples (Figure 7) present a more regular structure; the last has "a bizarre construction due to the irregular shape of the main elements, which are thus distributed to save timber", because "the Dutch often build their floors […] without regard to symmetry".

Even if he does not cite the reference, Krafft presents a floor that faithfully reproduces the Serlio model. It is a floor built in the pleasure castle of the *stadhouder* (Dutch lieutenant, precursor of the king), called the house of wood.

In all these references Krafft underlines the important role of the planking, often placed in double layer with crossed directions and staggered joints; in the case of the Dutch floor with irregular framing, Krafft highlights that a second plank is applied from below as to form the ceiling, thus hiding the structure's poor symmetry, but also reinforcing it. In addition, Krafft shows the example of a floor built in Amsterdam only with boards in three layers with an initial counter-deflection (Figure 8).

Krafft's second and more detailed work is his *Traité sur l'art de la charpente théorique et pratique* (1819) in which he also deals with the theoretical aspects of timber constructions. In this book between floors sustained by arches made of small pieces of timber, he presents a new example of complex floor, built in the *Reine Blanche* castle next to Viarme. It is again a floor with diagonal beams, but it differs from the others already shown because it is made of a series of concentric octagons, each of which is formed by increasingly shorter joists going from the perimeter walls towards the middle of the floor, which is rotated by 22.5° compared with the previous one.

Rondelet in his vast *Traité théorique et pratique de l'art de bâtir* dedicates the fourth tome to carpentry (Rondelet 1810). He shows how to achieve the original model of the Serlio floor, showing the various options for the joints (tenon-mortice or lap joints) and giving the dimensions of the joists, whose thickness – he writes – should be 1/18 of the span (and not 1/24 as in ordinary floors) to take into account the loss of resistance due to the joints. He also shows an example of the Serlio floor using one single elementary module (Figure 9).

For this floor Rondelet indicates reinforcing the joints between joists and beams with iron nails, and those between one beam and another with iron strips fixed with screws.

Rondelet also describes a Serlio floor in which the beams of the framing are placed diagonally, and in each square area defined by the beams there is a system of

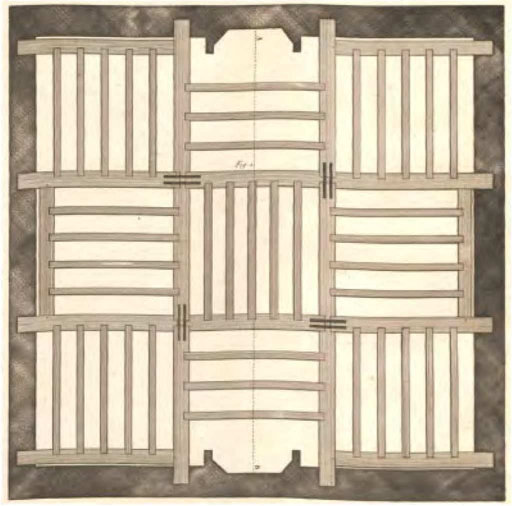

Figure 9. Serlio floor made of a single elementary module (Rondelet 1810).

two crossing layers of joists simply overlaid. This floor is said by Emy (1837) to have been built in Corbeil. In addition to these examples, Rondelet reports on almost all the floors shown by Krafft.

In his *Traité de l'art de la charpenterie*, Amand Rose Emy (1837) shows only floors already described by Krafft or Rondelet, but he gives an interesting clue about the origin and possible dissemination of the elementary principle underlying the Serlio floor. In fact, Emy affirms that "It is imitated from an amusement which one finds in an old collection of mathematical recreations, which consists in placing three or four knives, so that the ends of the handles rest on fixed points, and their alternately crossed blades can support an object in the air".

6 FLOORS WITH SHORT BEAMS OUTSIDE FRANCE IN THE 19TH AND 20TH CENTURIES

The enthusiasm for short beam ceilings that characterized the last decades of the 18th century and the early 19th century in France does not seem to be shared elsewhere.

In the various works by Peter Nicholson on carpentry, the only reference to the floors with short beams is in his *Dictionary of Architecture* (1819). In it, Nicholson gives a concise mention of this kind of floor under the entry "carpentry", citing Serlio and Wallis, and he provides a drawing in a plate.

In contrast, the judgment given by Tredgold (1820) is clearly negative: "There are many curious methods of constructing floors with short timbers, which cannot be passed over without notice, and yet are scarcely worthy of it; because they are seldom applied, as long timber is always to be had. To those, however, who are more inclined to pursue curious rather than useful information, the following notices respecting such floors may be acceptable". Tredgold's direct words clearly show that short beam floors were considered a mere curiosity with no real applications by British architects.

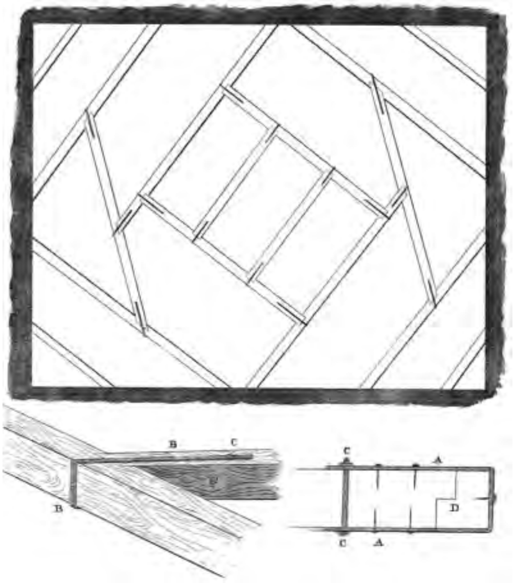

Figure 10. Drawing by Giuseppe Valadier (1831) of a floor built with beams shorter than the span to be covered, and details of the reinforcement of the joints with iron straps.

Even the Italian authors show a certain distrust for short beam floors. Giuseppe Antonio Borgnis (1823) – an Italian author who published his work in French – shows both a Serlio floor (composed of a single elementary module) and a floor with diagonal beams. Brognis affirms that "Serlio's method is simpler, stronger, and more regular" and that in the floors with diagonal beams "the pieces that compose this framing form more or less acute angles and irregular compartments: the whole load of the floor is supported by the small number of pieces that rest on the walls". Nicola Cavalieri San Bartolo (1826) – perhaps drawing his cue from Borgnis's considerations – arrives at similar conclusions.

Valadier's (1831) opinion on the floors built with short beams is sharper and certainly negative. In fact, he affirms that "this sort of construction can be regarded as more ingenious than good, since it is a concatenation of woods in which one brings the other, if one is missing everything goes bad [...] so if these floors are accessible, very little is to be trusted and therefore such inventions must be regarded as riddles". However, he gives the details of the joints, highlighting the necessity of strengthening them with iron straps fixed with nails and bolts in order to limit the extension of the notches in the principal beams.

Mazzocchi (1871) shows and discuss all the examples from Krafft, Rondelet and Emy and criticizes these floors for risking collapse due to the break of a single joint. He thus encourages the use of iron elements for their reinforcement and higlights the role of planking. Curioni (1868) shows the Serlio floors already described by Rondelet, paying attention to the importance of reinforcing the joints with metal straps and all the floors with two crossed layers of boards; he also expresses his poor opinion of diagonal beam floors, repeating the well-established criticisms. Instead, Caveglia (1878) gives his preference to the floor with diagonal beams, since "when each beam has suitable dimensions, it can present great strength", while the resistence of the Serlio floor is "essentially based on the rigidity of the joints", however he says that these floors "have lost importance, since iron beams are much more convenient than wooden ones for large floors".

From then, floors with short beams were mentioned in almost all Italian treatises and manuals on buildings, up to the middle of the 20th century, always proposing them as alternatives, but also affirming the greater rationality of steel and reinforced concrete floors.

7 CONCLUSIONS

It is difficult to understand what real diffusion this type of structure has had over time: floors with short beams are more of a literary feature than a real chapter in the history of buildings. Very few cases still exist or are described in documents and publications. It is possible that others exist, hidden from view by ceilings, and others have existed and are now lost due to collapse or demolition, which is likely given the particular constitution of these floors. One of the known floors is that of the Music Room of Palazzo Piccolomini, built by Rossellino in 1461; perhaps it was known both to the Tuscan Leonardo and to Serlio, due to his close relationship with Baldassarre Peruzzi (Beltramini 2018). Bisconcini (1925) states that Serlio would have used this technique in the church of San Sebastiano in Venice (where he lived between 1528 and 1541) but recent studies do not cite his intervention in that construction (Beltramini 2018). Apart from the model by Wallis in England, only some late 16th and 17th century examples of floors built with short beams are reported to have been built (Gargiani 2012; Yeomans 1997, 2012) (Figure 10).

The only place it seems to have been popular is the region between the Netherlands and Paris between the end of the 18th and early 19th centuries. A series of concomitant factors, occurring for a limited time, favoured the effective employment of a technique already known at a theoretical level, which for centuries had been circulating across Europe through the practice and books of carpenters and architects: the availability of low-cost planks (the result of mechanical sawing), permanence of traditional carpentry skills, and cheap labour, reduced the cost of the iron necessary for reinforcing joints and effectively nailing the planking.

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History of Construction Cultures – Mascarenhas-Mateus & Paula Pires (eds)

Historic bell frames – regional traditions and transregional influence

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ABSTRACT: An investigation of bell frames in the German Federal States of Thuringia and Saxony-Anhalt has revealed specific basic types. Modification of these types took place for different reasons. It became clear that certain areas were limited to a single design typical of their respective region, the use of which became an established tradition. These traditions were informed not only by the locally available building materials, and thus the climate, but also by the repeated reuse of designs that had been proven in the past. This approach is evidenced in construction documentation and in other sources. Prior to the appearance of treatises on carpentry, there is archival evidence of transregional influences on bell frame designs through knowledge transfer between craftsmen, influences that are also evident when viewing traditional designs. A distinctive aspect of the wood structures examined in this paper is the close collaboration between bell casters, who generally worked transregionally, and specialised carpenters.

1 INTRODUCTION

Ringing bells hung on frames high up in wooden towers is a European tradition closely linked to the Christian faith and these bells spread along with the knowledge of how to cast them with distinct tonal ranges. Several bells tuned to one another form a ring, for the hanging of which a special structure, a bell frame, is needed. This paper deals with bell frames in continental Europe with a special emphasis on the German Federal States of Thuringia and Saxony-Anhalt and draws comparisons with the Netherlands, Switzerland, and France (Engelmann 2015). Written sources include publications mostly about individual objects (e.g. King 2015, Peter 2014a), selected archival documents from the 18th and 19th centuries, as well as construction-site documentation from the 15th and 16th centuries. The bell frames themselves are, however, an essential source of information. Through research and the usual documentation methods, 130 bell frames were recorded in detail and incorporated into this comparative study. Included in the study are surviving wooden structures spanning the early- to late-13th century and all the way up to the increased use of steel bell frames starting around 1900.

Research on historical wooden bell frames is quite a young discipline. Although detailed research has been ongoing since the 1940s in Great Britain (Drew-Edwards & Lodge 2003; Elphick 1945; Pickford 1993), in continental Europe the last extensive paper on these structures was written one 100 years ago, in 1921, by Heinrich Biebel (Biebel 1921). The author analysed bell frames, mostly in city churches, but only within the borders of the former German Reich. An extract of his work was published in the *Zeitschrift für Bauwesen* but the full research paper has been lost until today.

What does a bell frame have to do? First, the bell frame supports the ring, which means it must support an enormous static mass. The largest, free-swinging medieval bell in Germany, which is also rung regularly, is the Gloriosa in the Erfurt Cathedral. It weighs 11½ metric tonnes and has a diameter of more than two and a half metres. Second, the bell frame must absorb the dynamic loads of the swinging bells. When the Erfurt Gloriosa is rung, a force equal to three times its weight is applied to the structure when the bell is at the bottom of its swing. In this case, the load on the bell frame is 34½ metric tonnes. Furthermore, the loads have to be redirected through the massive tower structure – preferably at a very low part of the massive structure to avoid damage to the tower caused by the oscillating forces. Therefore, the bell frame must not be in direct contact with the tower structure at any single point. It must be freestanding – like a piece of furniture – on its own supporting structure. The larger and heavier the ring, the higher the forces that must be absorbed and the more demanding the design. In order to absorb such loads and transfer them to the tower structure in a damped manner, certain basic structures were developed. The basic design of these constructions did not change from the Middle Ages until around 1900.

2 TYPICAL DESIGNS

Historic bell frames are usually made of wood – very often of oak wood, because it is particularly hard and durable compared with coniferous woods. However, elm was also used for bell frames, where it was locally

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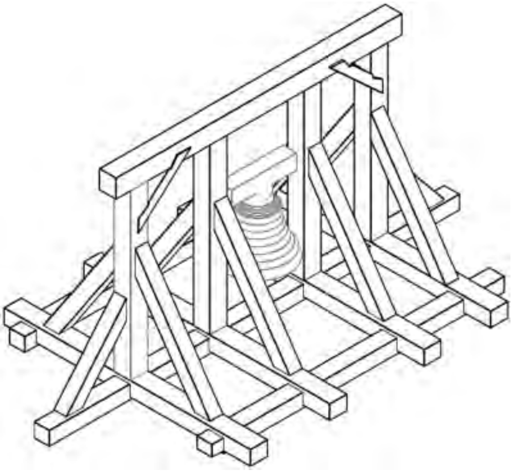

Figure 1. Typical king post construction. Drawing: Iris Engelmann/VG Bild.

available (Höhne 2013). It was not until the late 17th century that there was increased use of coniferous woods, particularly spruce and pine. The basic static system of bell frames is the truss since the primary goal is to transfer the primary loads – namely those of the bell – to the base of the braces. From there, they are directed further outwards to the tower walls or to the base of the tower. In its simplest form, the truss can be described as a king post truss design (Figure 1). If the structure is mounted in a frame, it forms a box structure (Figure 2). Compared to box-type designs, king post truss designs can be built in a way that uses much less wood, since the additional uprights, the long transverse frames and heads, as well as additional braces within the trusses are not required (Engelmann 2015).

The main load-bearing joints were designed to withstand compression from the very beginning. This applies to the connection between the braces and the sill, in particular, as well as to the king post.

Only the transverse timbers (perpendicular to the swing of the bell), feature lapped joints, up to the 16th century, which were capable of absorbing tensile forces. The bell frame structures studied so far can always be traced back to one of the above-mentioned basic structures. In the following treatment, several modified designs typical in certain regions are presented in greater detail.

3 REGIONAL TRADITIONS

The first question that arises is how regional traditions in structural timber engineering developed. That is, how did designs with similar shapes, proportions and dimensions arise? One aspect was the availability of building materials – in this case, of suitable structural timber. The types of timbers that were available and their dimensions was, in turn, significantly influenced by geographic and climatic conditions (Eissing 2009, 71). The climate was therefore a factor in the development of regional traditions.

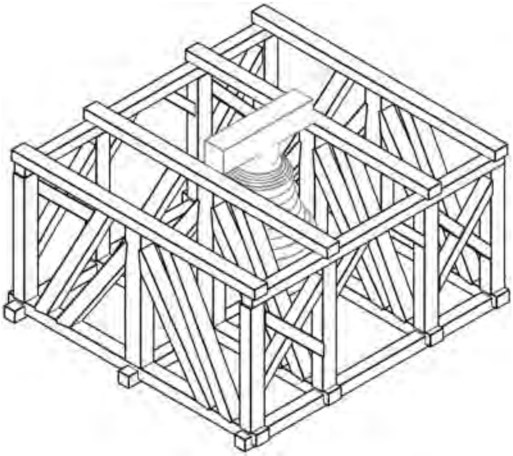

Figure 2. Typical box-type construction. Drawing: Iris Engelmann/VG Bild.

3.1 *Climatic conditions*

When we take a closer look at the inventory of bell frame designs in today's Thuringian region, we can observe the following specific distribution: king post truss structures with a low timber requirement can be found almost everywhere, whereas box structures with a higher timber requirement can be found especially at the southern periphery of the Thuringian Forest as well as in the Thuringian Basin and along its fringes. This coincides with the regions that have a high occurrence of oak trees in a relatively dry and warm climate (Bayerl 2000; Bricks 1997; Witticke 2005).

In contrast, softwood timbers (conifers) dominate in the more humid and cooler regions of Thuringia – in the Thuringian Highlands, for instance, and the Thuringian Forest. Hardwood is quite scarce in these areas and oak is not found at their high altitudes. In these regions, procuring oak wood was laborious and more expensive due to long transport distances, which is why more material-efficient structures such as the king post truss design were used.

In one part of the Thuringian Basin, high wood consumption is particularly apparent due to the use of enormous oak cross-sections. Moreover, a unique bell frame design was established here in the 16th to 18th centuries. Between Heldrungen and Weissensee, only box structures are evident. Four bell frames with similar proportions and structural details stand out and are all located within a ten-kilometre radius: Leubingen 1516/17 (d) (Figure 3), Gorsleben 1591(i), Günstedt circa 1716, Kindelbrück 1784(i).

These bell frames feature two posts under the frame head and timbers with very large cross-sections. On average, the posts have cross-sections of 20 to 25 centimetres to a side, while in Leubingen the cross-sections measure a considerable 45 x 30 centimetres.

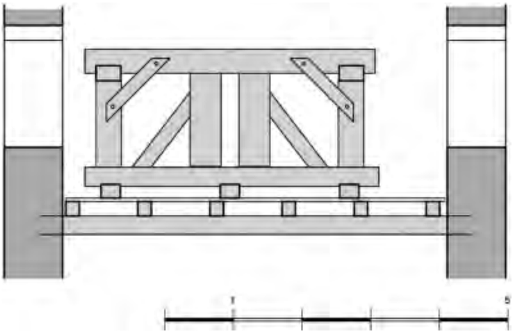

Figure 3. Leubingen, bell frame, 1516/17(d). Drawing: Iris Engelmann/VG Bild.

In general, Thuringian bell frames with posts that have particularly large cross-sections, i.e. more than 1000 square centimetres, are located in north-western Thuringia and were built primarily between 1470 and 1530. It is notable that the smallest cross sections occur in central and southern Thuringia and generally in the 18th century. These observations ultimately confirm Eissing's statement that maximum structural timber cross-sections depend on the available trunk diameter, which is influenced by the species of wood – in this case, primarily oak – the age of the trees, the location and position in the stand, as well as the type of forest management and climatic factors (Eissing 2009).

3.2 *Preceding structures*

Another aspect of how regional traditions are created is certainly a repeated reference to existing structures and thus to established, proven designs. Building records show that carpenters used bell frames they encountered as models for new ones. Here are two examples from the 18th and 19th centuries, each of which concerns the construction of a new bell frame: a letter dated 1767 from the municipality of Rockhausen to the Arnstadt Consistory states that parts of the old bell frame should be reused in the new one and that the new bell frame should be built in the same manner as the old one, "(…) Was zu den Neuen Glockenstuhl ohnumgänglich erfordert wird, nehmlich: 15 Stück Eichen, jedoch den alten mit eingearbeitet, und nach der Art des Alders zuverferdigen…" (ThStA Rudolstadt, 11406). The text of the letter emphatically underscores the statement that the previous design should be retained and salvageable parts reused where necessary for cost reasons.

The second example from 1869 also discusses the reuse of an existing structure (ThStA Rudolstadt, 0904). The municipality submitted the estimate and the drawing of master carpenter, August Thomas of Achelstedt, to the Rudolstadt building authority for review. The carpenter noted in the documents that the model for the drawing of the new bell frame was an existing bell frame: "Herstellung eines neuen Glockenstuhls für die Gemeinde Großhettstedt" "Derselbe [der Glockenstuhl] soll nach dem beigelegten Risse, welcher nach einem schon bestehenden Glockenstuhl gemacht worden ist, ausgeführt werden". Accordingly, the master carpenter modelled the new bell frame on another one with which he was already familiar, which he then adapted to the situation in Grosshettstedt.

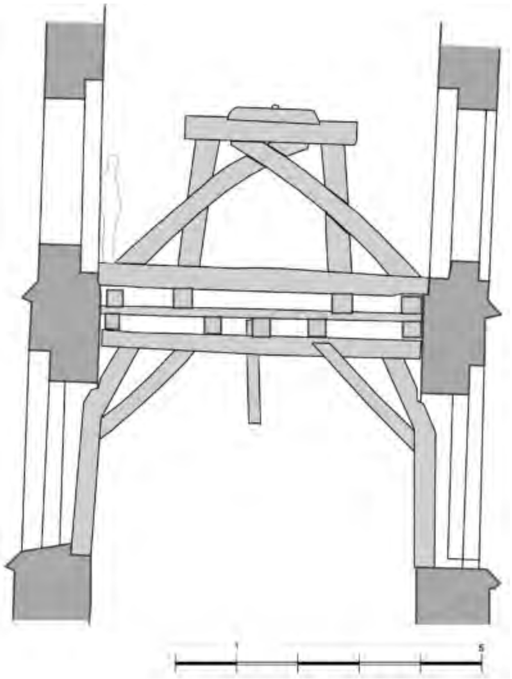

Figure 4. Mühlhausen, Divi Blasii, north tower bell frame 1461/62(d). Drawing: Iris Engelmann/VG Bild based on a building survey in: Thüringisches Landesamt für Denkmalpflege und Archäologie, Bau- und Kunstdenkmalpflege, Archive reg. 64.066-003 Divi-Blasii Kirche Mühlhausen, map no.: 25/92, catalogue: building survey 15.5. – 09.9.1991 north tower, Michael Henkel, Stefan Roser, Tanja Schrwirko.

Based on these archival references to previous structures, it is reasonable to assume that similar approaches were also common in the 15th and 16th centuries. This is evidenced by preserved structures in other belfries. We can thus infer that the bell frame in the north tower of Divi Blasii in Mühlhausen, 1461/62(d) (Figure 4), and the lower bell frame of St Stephani in Bad Langensalza from 1518/19(d) with structures atypical for their respective periods resemble previously dismantled bell frames; that is, that the new bell frames were built in the style of the old ones. In both cases, the older substructures –Mühlhausen: 1434/35(d), Bad Langensalza 1436/37(d) and, in Mühlhausen, also the older bell from 1345(i) – were preserved. The frames themselves – both box designs without king posts – presumably draw on the scissor-brace designs familiar in medieval roof structures (Engelmann 2015).

Due to the tradition of perpetuating familiar designs, structures with specific characteristics persisted in some regions. I will discuss three regions and take a more detailed look at the Thuringian example.

1) According to Heinrich Biebel, the curved braces and noggings in combination with keyed tenon joints and racking struts are typical of the Lake Constance area. Thus, in his opinion, the bell frame in the north tower of the cathedral of St Nikolaus in Überlingen am See (Figure 5), built in 1585, is, “A masterpiece of German carpentry, whose compositional characteristics had a decisive influence on future works in the entire Lake Constance region” (Biebel 1921, 99).
2) For the canton of Zug, in Switzerland, Josef Grünenfelder documented 17 bell frames from five centuries, which all look similar (Grünenfelder 2000). These are variants of the box-type bell frame with an inscribed king post truss design and end posts that extend beyond the head. This means that in this 240-square-kilometre area, a frame design specific to the region was preserved from the Middle Ages until the 20th century.
3) A special feature in Thuringia is the area along the rivers Saale and Orla. This area is distinguished by the prevalence of queen post structures, a variant of the king post truss design in which a straining beam is fitted between two upright posts, which holds the bell bearing (Figs. 6, 7).

The earliest such queen post structures in Thuringia can be found on the Erfurt Cathedral Hill in the central tower of St Severi. The timbers for the bell frames were felled in 1472-3(d) and 1473-4(d). These structures were probably the model for the first bell frame in the Saale-Orla area mentioned above. In 1477(d) the four-field bell frame for the parish church in Neunhofen, the main church of the Archdeaconate of St Marien, was built. A further 22 queen post structures have so far been documented in the vicinity of Neunhofen.

Yet neither king post truss nor box structures have been observed in this area. Remarkably, for the first time in Thuringia, queen post structures appear at the same time and in the same region as roofs built in the liegender Stuhl design. The structures are very similar in their static effect in that the loads are directed outwards via racking struts. For example, in Neunhofen is the earliest if not fully developed liegender Stuhl in Thuringia, dated 1459-60 (d) (Eissing 2009, 204).

An apparently significant finding is that the area along the Saale River stands out from the western part of Thuringia both in roof design and in the design of bell frames at the end of the 15th century due to innovative approaches to construction (Figures 6 and 7).

Whether the influence in the late 15th century in bell frame construction is traceable to southwest Germany, as is the case with roof design, is still a matter of speculation, as the Bamberg Cathedral also has a queen post structure dating from 1442 (Peter 2008, 65–73) which could have been the model for the Erfurt structures. t can therefore be assumed that there was a transregional influence before this innovative modern design became established in the Saale-Orla region which developed over centuries as a regional tradition.

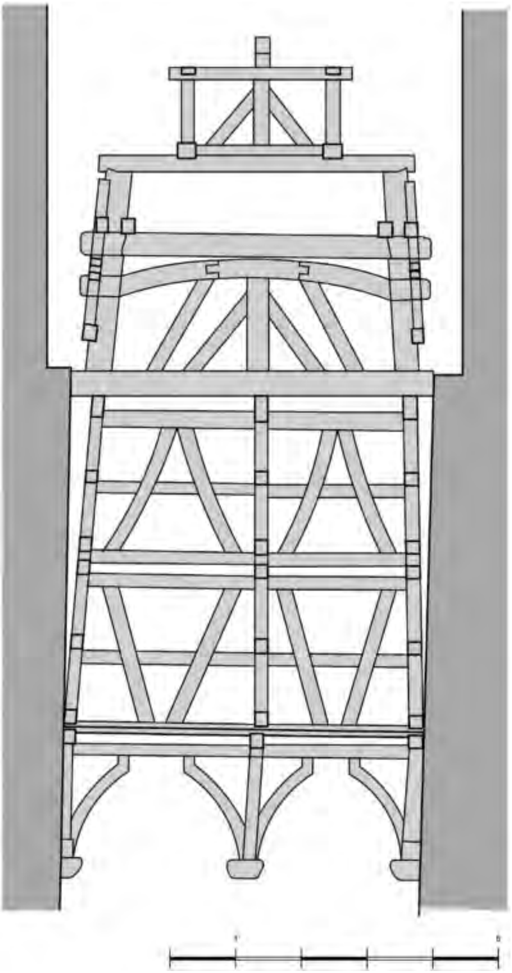

Figure 5. Überlingen, St. Nikolaus am Bodensee, north tower bell frame with curved braces and noggings as well as keyed tenon joints. Drawing: Iris Engelmann/VG Bild based on an original by Biebel 1921, plate 5, Figure 5.

4 TRANSREGIONAL INFLUENCE

4.1 *Carpenter treatises*

Starting in the 17th century, the transregional transmission of carpentry knowledge and experience was supplemented by printed accounts. Since the advent of treatises on the art of carpentry (Holzer 2009), bell frames, along with depictions of roofs, half-timbered buildings, bridges and lifting devices, have been an integral part of compilations showing examples of selected designs. Most of these works contain illustrations of typical contemporary bell frame types, which,

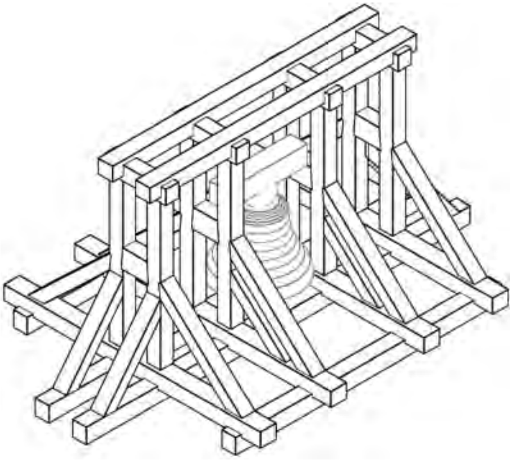

Figure 6. Typical queen post construction. Drawing: Iris Engelmann/VG Bild.

depending on the background and origin of the author, show typical regional solutions in their joinery and details (Holzer 2009, 185).

Initially examples were shown without attribution to a place or author. Only in the engineering books of the 19th century were the presumably non-localised examples supplemented by built local examples, which were usually erected just a few years prior to publication. Here I would like to mention two selected works:

Johann Wilhelm's *Architectura Civilis* presents the first treatise on "the carpenter's art" in the German-speaking world in 1649 (Holzer 2009, 177) and is intended as a reference for the transfer of knowledge from craftsman to craftsman.

Although the concise texts and isometric or perspective drawings were not sufficient for self-study alone, or for imitation without training provided by an experienced master carpenter, this treatise was used as a drawing and design template for apprentice carpenters (Holzer 2009, 179). The master carpenter Johann Wilhelm, who was originally from the Vorarlberg region of Austria and resided in Frankfurt am Main (Oechslin 1973, 56f), depicts three sparsely annotated bell frames in his textbook on structural engineering. The first copper engraving shows a box structure with an inscribed single king post truss design, as it is generally also found in Thuringia (Figure 8). Typical for the 17th century are the racking outer posts and the profiling of the timber heads and associated structures like bearing blocks. Also, the se cond illustration of a box structure with a multiple braced truss is also a Baroque form of the bell frame often found in Thuringia, especially in areas rich in forest, as well as in Eisfeld (Figure 9). The third illustration may be a regionally specific design of a king post truss structure, which has not been observed in Thuringia up to now (Figure 10).

It depicts a bell frame with short heads resting on the main braces via corner braces. A nogging piece inserted through the posts and braces is secured with keyed tenon joints.

Figure 7. Kahla, St Margareten, bell frame, 1495, queen post construction. Photo: Iris Engelmann 2012/VG Bild.

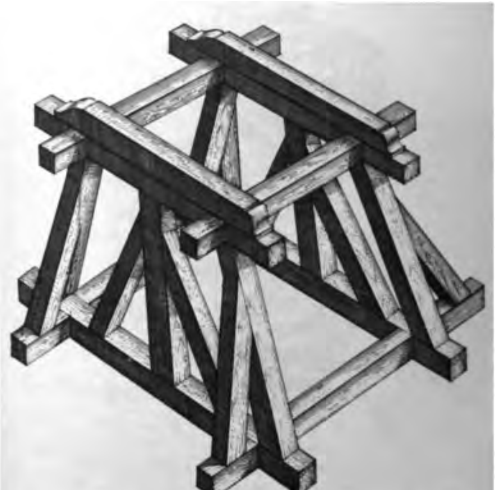

Figure 8. Box construction with an inscribed king post, racking outer struts and profiled bearing heads. Wilhelm 1668, part 1, no. 23.

The publication by Theodor Böhm shows that these treatises not only provide information on structural details, but also convey modern insights into the use of materials. In 1911, he refers, among other things, to

Figure 9. Box construction with numerous braces in the truss.

the bell frame in Notre Dame in Paris, which Viollet-le-Duc modelled on a medieval bell frame, but also provides an exemplary description of the pure larch wood construction of the Gothic bell frame of St Nicholas Church in Innsbruck, which was removed in 1851 (Böhm 1911, 624). This dedicated discussion of softwood structures is also reflected in the use of different species of wood across regions, not only that of Thuringia. From the end of the 18th century onwards, pure coniferous wood structures began to appear, which became increasingly common in the 19th century. Although this literature was widely distributed and known transregionally, it is clear that the selection of the printed specimens was influenced by the author's origin, education and experience. Thus, the basic forms were disseminated and copied across regions, while certain details were adapted to local traditions. Prior to the advent of printed carpentry treatises, knowledge was passed on directly by carpenters across regions. The archival records from construction sites and surviving medieval bell frames provide information about this period. Two particularly interesting examples from the time around 1500 are examined in more detail below.

4.2 *Erfurt*

As already mentioned, the church towers of St Severi in Erfurt have housed two queen post structures since 1475. Some 20 years later, two new bell frames were needed for the bells cast in 1497 by the Dutch bell founder, Ghert van Wou (Bund & Peter 1990). One of them was the Gloriosa for the Cathedral of St Mary in Erfurt, mentioned at the beginning of this paper, and the other was intended for the north tower of St Severi. Both bells were suspended in box structures (Figure 11), a construction method not noted in this region until that time. As noted above, also in the nearby Saale-Orla area since 1477, only queen post structures were built for large bells, e.g. in Neunhofen 1477, Neustadt an der Orla 1480, Kahla 1495 and Rudolstadt 1499 to name just a few (Engelmann 2015). So, what led to the decision to use this novel box construction here in Erfurt?

The Dutch bell expert, Sjoerd van Geuns, demonstrated close cooperation between the bell founder, Ghert van Wou, and the master carpenter, Andries Goyertzs (Geuns 2000, 84). Both probably worked together on five different rings: before van Wou received the Erfurt commission, there is evidence of collaboration in Kampen (1481) and Genemuiden (1488), then in Zeerijp (1502), Utrecht (1505) and Brunswick (bell casting 1502, bell frame construction from 1506, Peter 2014b). A collaboration between van Wou and Goyertzs can also be assumed in Stendal (bells 1490, box bell frames 1482 +/-10 (DAI 1997). As van Geuns describes, the construction invoices of Utrecht Cathedral show that Master Andries was commissioned as the expert for the complete construction of the bell frame. He was responsible for the delivery of all the necessary timbers, for the construction of the bell frame, the raising of the bells, the hanging of the bells in the frame and the installation of the acoustic reflector, Geuns (2000, 84f). Andries was brought in along

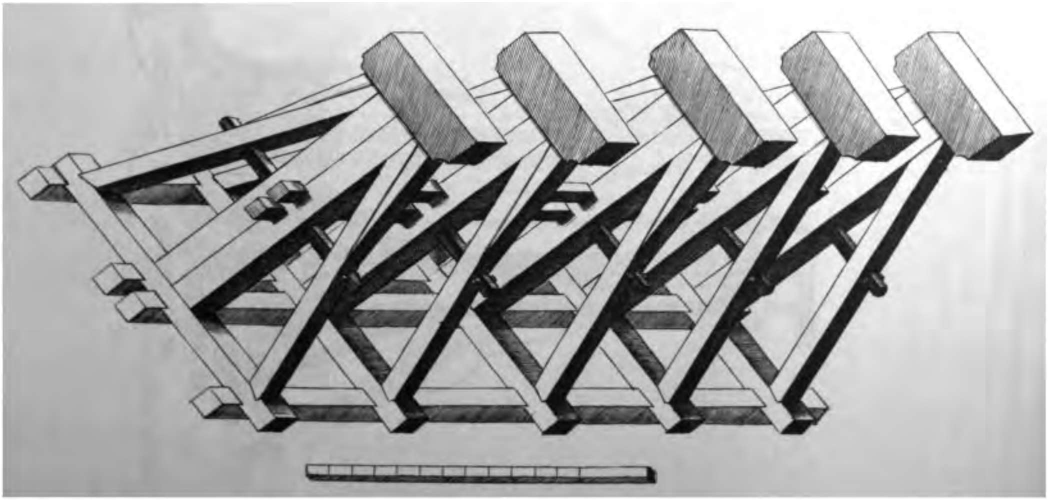

Figure 10. King post construction with short heads. Wilhelm 1668, part 2, no. 21.

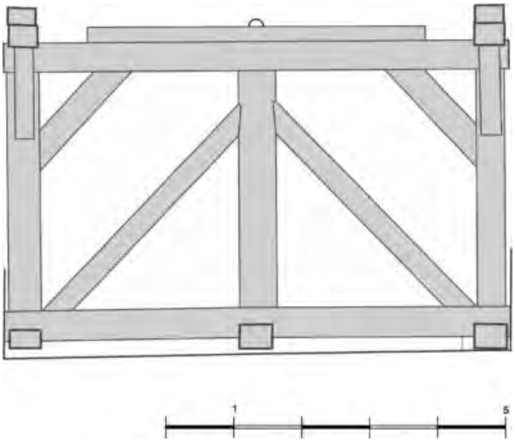

Figure 11. Erfurt, St Severi, north tower bell frame 1499. Drawing: Iris Engelmann/VG Bild.

with the master carpenters already contracted specifically to build the bell frames. Although his name is not mentioned in the Erfurt construction invoices from 1496 to 1506, a collaboration between the two Dutchmen can be expected in Erfurt as well, as the Erfurt structure bears a strong resemblance to the bell frames in Stendal, which had been built shortly before, as well as those in Utrecht. It can be assumed that local master carpenters had no experience with such enormous rings, which is why those supervising the construction at the Erfurt Cathedral decided on the box design preferred by van Wou. At any rate, there are no known medieval box bell frames in Erfurt or in the surrounding area. The new box structure on the Cathedral Hill in Er furt was probably not copied in the immediate vicinity of Erfurt.

4.3 *Constance – Basel*

Even during the construction work on the Konstanz Cathedral, the local construction supervisors did not commission a local carpenter for the bell frame, but instead enlisted the help of one from Basel, who had already gained experience on the construction of the cathedral there. He is mentioned in the construction documentation as master carpenter Hansen, “*werckman des stiffts zu Basel”*. He was commissioned in 1498 to level the ground for the initial fitting of the bell frame and was brought back to Constance in 1509 to erect the bell frame in the tower, (Reiners-Ernst 1956, 35,55; Laule 2013a, 255f.). In the same period from 1488 to 1500, the upper floors of the St Martin’s Tower at Basel Cathedral were finished (Meier 2019, 132f., Stehlin 1895, 193, 201f.). After the 1511 tower fire in Constance, two more bell frames and bells were needed. Although a carpenter from Lindow lobbied the construction authorities to be granted the bell frame commission for the north tower in 1513, the supervisors once again paid “*Meister Johannes Im Hoff”* of Basel for four days to build the bell frame in the accounting year 1513-4 (Reiners-Ernst 1956, 63; Laule 2013b, 258). With the supervisors’ decision in May 1515 that the second tower should also be completed by autumn, Hans of Basel returned to Constance for the bell frame (Laule 2013b, 258). Therefore, Master Hans of Basel travelled from Basel to Constance at least four times specifically for the bell frame and was hired as a specialist. This example again demonstrates that bell frames were made by specialised carpenters and that experienced craftsmen were also brought in from other regions for major projects.

5 CONCLUSION

Building a bell frame was often a considerable challenge, and it is reasonable to assume that carpenters initially oriented themselves on existing structures or sought out proven examples of such in the immediate vicinity to serve as models for the new structure. As a result, recurring principles and details can be identified within the immediate vicinity of one another. This is clearly evident in the canton of Zug in Switzerland and in the Saale-Orla region of Thuringia, where the tradition within a broad area revolves around a single design. Copying existing, time-tested bell frame designs seems to have been the rule in locally circumscribed areas. These structures were adapted to the local conditions and built using joints and ornamental elements typical of the respective periods. The influence of master craftsmen such as bell founders or carpenters working across regions is particularly evident on large construction sites.

ABBREVIATIONS

d	Dendrochronologically dated
i	Dated by inscription

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History of Construction Cultures – Mascarenhas-Mateus & Paula Pires (eds)

Large span timber roofs in Italy between the 16th and 19th centuries

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ABSTRACT: This paper depicts some characteristics of long span roofs in Italy between the 16th and early 19th centuries, with the aim of highlighting the transregional and transnational transmission of knowledge during this period. The article is based on documentary analysis and building surveys and analysis of manuals and publications of the time. Different practices in Italian regions are considered and compared, especially the roof structures of churches in Bologna, an area of particular importance because of its location. Until the start of the 19th century the design and construction of this roof type was primarily based on direct experience and practice. From then, the design and verification of trusses derived from theories of the new-born Building Science. This paper aims to bring together some of the previous literature, mainly focused on specific buildings and specific regions, to highlight cultural ties, influences, technical references, and derivations, between regions.

1 INTRODUCTION

In general terms, historic Mediterranean roofs differ from those of northern European regions in two main ways: the reduced slope of the roof and the use of suitably arranged series of timber trusses, each consisting of a limited number of large elements, mostly made of hardwood like oak but also of softwood like fir or larch.

Andrea Palladio talked about timber roofs in chapter XXIX of the first of his renowned Four Books of Architecture: “These ridges ought to be made higher or lower, according to the regions where one builds; therefore in Germany, by reason of the great quantity of snow that falls there, the roofs are made very acute, and covered with shingles, which are small pieces of boards, or with very thin tiles; which roofs, if they were otherwise made, would be destroyed by the weight of the snow. But we that live in temperate regions, ought to chuse that height which makes the roof appear agreeable a with a beautiful form, and that easily carries off the rain […] [sic]” (Ware 1738). The slope suggested by Palladio and used for his buildings is around 24°: the breadth of the place to be roofed is “divided into nine parts, and two given to the height of the ridge”. The smaller number of structural elements and the frequent use of hardwood in Italian trusses entails a reduced number of connections and a simplified manufacture of the joints compared with European examples of the same period. The result is having structures with a lower degree of static indeterminacy – according to today’s structural vision – or even potentially unstable with respect to horizontal loads. In this paper we analyze timber roofs with large spans, those larger than 13–14 meters, from the late 16th to the early 19th centuries. Structures above these dimensions involve complex configurations, often resulting in unique cases which are more the product of the intuition of their builders than the repetition of established schemes handed down over time.

2 THE ITALIAN TRUSS

For spans under 13–14 meters, roof structures take on rather repeated forms, obviously with some variation, according to the Italian truss scheme, or *capriata*. It should be remembered that this peculiar Italian term appeared only in the 19th century to indicate trusses of any material which followed the so-called principle of the non-deformable triangle. In fact, it was not until then that structures started to be conceived as reticular beams, with elements in compression and others in tension. Before that period, timber roof structures were generically referred to as trestles (*incavallature, cavalletti*, from the French *cheval*), as frameworks, or armatures (*armature*), and were not verified through analytical methods.

Simple (or classic) Italian trusses are historically characterized by the tie beam, the king post in tension and two struts in compression, added to reduce bending in the rafters (Figure 1). In the classic scheme the king post is detached from tie beam and the two are connected by U-shaped metal straps. In such a way the vertical load is not transferred to the tie beam, which

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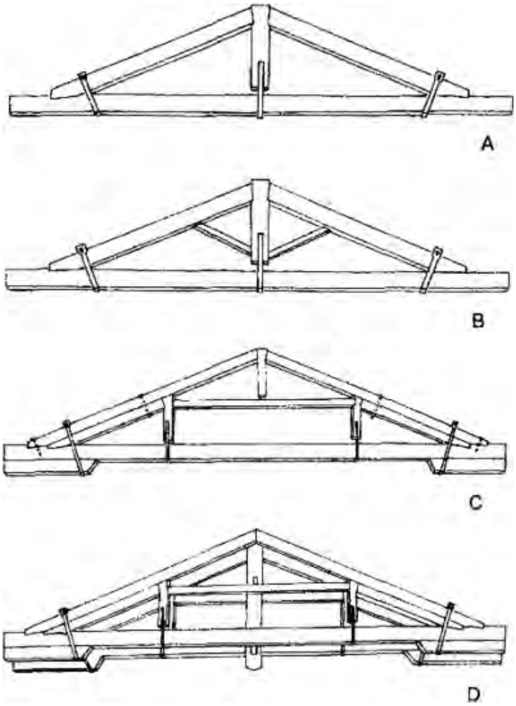

Figure 1. A. *capriata* with a king post only; B. classic Italian truss, or *capriata* with king post plus braces, or struts; C. simple *palladiana*; D. double *palladiana*. From Valeriani, 2003.

only has to resist the outward thrust from the principal rafters in addition to the load of its own weight. This scheme works especially if the trusses are assembled on the ground, in such a way that the tie beam is not subjected to any bending, and then raised up to the roof. Above 10–12 meters the trusses are usually too heavy to be lifted in one piece; therefore, they are often equipped with a collar beam and queen posts and lifted element by element, taking the name of Palladian trusses (*capriate palladiane*). In Palladio's Four Books there is evidence of drawings with such trusses, even if it is not clear for us how they were built; the popularity of the term *palladiane* is probably derived from the reputation of the architect. Unfortunately, the terminology is still confused today, as many authors refer to Palladian trusses as classic types.

The long-debated issues related to Italian trusses concern the post to tie beam problem, the use of metal connecting elements, the problem of building composite beams and the case of structures with discontinuous rafters (Valeriani 2003).

Italian architects were aware that the tie beam should not be loaded by the posts acting in compression in order to reduce its bending. They often referred to the detachment of the king post from the tie beam as "open joint" (Valeriani 2005) whereas G.B. da Sangallo depicted a *capriata* with a detached king post (*columna*), accompanying his translation of Vitruvio's *De Architectura* in 1539. The same mechanism of the open joint was better explained in a sketch by the scientist Bernardino Baldi in *Mechanica Aristotelis problemata exercitationes*, published in Mainz in 1621, where the purpose of the king post with a metal strap was used to support the tie beam (Figure 2).

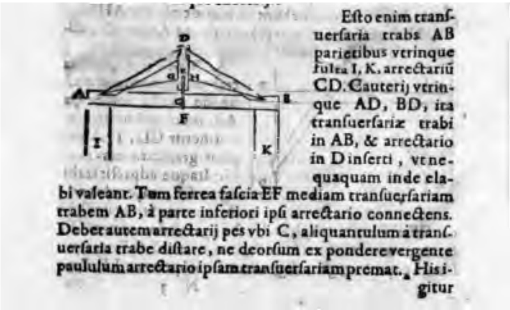

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Figure 2. B. Baldi, open joint (F) to counteract the bending moment in the tie beam. In *Mechanica Aristotelis problemata exercitationes*, Questio XVI, 102.

Palladio did not draw open joints in his trusses, representing only bolted connections. Moreover, he declared himself less confident about long spans: "[…] There are various manners of disposing the timber of the roofs; but when the middle walls support the beams, they are very easily accommodated; which method pleaseth me very much, because the out-walls do not bear so much weight, and altho' the head of some beams should rot, the roof is notwithstanding in no danger [sic]".

Since the role of metal connections is not explained in Palladio's books, it is difficult to give a clear interpretation of his poor details, especially because the drawings in the manual usually do not match with actual construction. Daniele Barbaro, friend of Palladio, also depicted *capriate* with "closed joints", interpreting Vitruvio's *De Architectura*. Across the centuries it has been possible to find this type of joint, where the king post is tightly connected to the tie beam and, consequently, is more or less compressed, forming a statically indeterminate structure.

Another issue is the discontinuity of the rafters. As said before, for spans over 10–12 meters and for construction purposes, in queen post trusses the rafters are often discontinuous and split into two parts. This solution derived from the necessity of building the structures using more steps, given the difficulty of lifting heavy pre-assembled trusses. At first, lower rafters, collar beam and queen posts were erected, forming a sort of compressed arch; then, the upper part of the rafters and the king post were placed on top of the first structure. Sometimes a second continuous rafter, connected directly to the king post, was placed on top of the first rafter. The latter scheme is more complex and rigid than the first, preventing the potential horizontal displacements of the collar beam. This solution reached maturity in the late 17th century, as can be seen from the drawings of Carlo Fontana (1694) and Nicola Zabaglia (1743).

At the end of the 16th century, another popular manual was the Seven Books of Architecture by Sebastiano Serlio, with the first incomplete edition published 1537. In particular, Serlio drew a table of “timber armaments” “to use for various things”, in order to determine the structures, making explicit reference to the Italian reality. The text reads as follows (book VII, chapter LXXIII, printed posthumously in Frankfurt in 1575): “[...] the IX figures that are seen here in front, they are in the way they are accustomed in Italy; of which (as I said) the master of lumber will know how to accommodate according to the places: for which I will not give other measures on this”.

In Serlio’s manual all the joints are closed, and the elements seem quite disproportionate. It is possible that Serlio was not particularly expert in timber construction, but it seems more likely that in the 16th century the sizing of the structures was entirely left to practice, even for big structures. The architects, working to an agreed general scheme, must have – at least partially – delegated the assistant or carpenter to order the materials and make the final selection of the timbers and typology of the joints. Palladio was definitely more focused than Serlio on this subject, although he never talked about pins or nails. Today, knowledge of the construction process, derived from a survey of real structures, is a key aspect in understanding the form and behaviour of Italian trusses.

3 LONG SPAN TRUSSES IN ITALY

At the end of the 16th century, the spans of many important buildings were enlarged. The new spaces to be covered were those of Counter-Reformation churches, great civic halls, great military structures, and, from the 17th century onwards, theaters. Until the early 18th century, the timber structures of the main Italian buildings were among the most significant in Europe and had some influence, for instance, in the design of Baroque churches in Germany (Holzer 2008) or classic buildings in England (Yeomans 1986). Unfortunately, carpentry manuals which had spread throughout France and Germany, places where timber was used extensively, especially for bridge construction, were not translated into Italian and the techniques derived from them apparently had little impact on Italian models.

There are numerous cases of large span roof construction in Italy around the beginning of the 17th century, well known at the time and still examined today, for the purpose of conservation. A comprehensive study has not yet been undertaken meaning all investigations are concentrated in specific regions. Larger span trusses imply the presence of secondary rafters and compound queen post trusses, or even special trusses, with unconventional design. For the purpose of this paper, these roofs are analyzed in two dimensions, although they are tridimensional structures and should be examined as such. Specific cultural areas can be identified with the presence of considerable roofs, characterized by variations of the Italian truss type, largely according to the Palladian scheme.

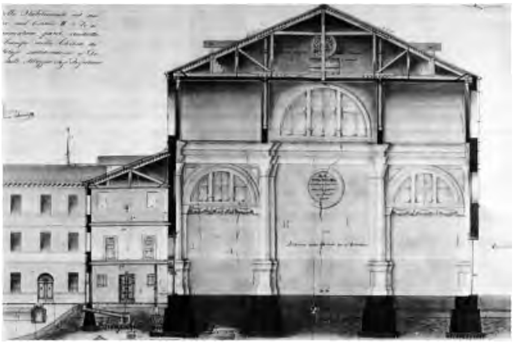

Figure 3. The enormous truss of the church of S. Lorenzo in Venice, near the Arsenale.

The Veneto region is among the most prolific in terms of production, with trusses made up of queen posts or king and queen posts; the joints are generally closed, as evidenced in the simple roof structures of Santi Giovanni e Paolo and Santa Maria dei Frari in Venice, both with a span of 13 meters.

Long span structures of Veneto are the compound Palladian roof of the Grand Council hall in the Doge’s Palace in Venice, with a span of about 25 meters, rebuilt after the fire of 1577 and restored in the mid-19th century; the roof of the Olympic theater in Vicenza, by Palladio; the timber roofs of the *tese* at the Arsenale (Menichelli 2009), spanning up to 25 meters, and other civil and military works. The *tese* were a series of sheds where watercrafts were built over the centuries, probably the biggest factories in Italy until the 18th century; in fact, maximum span was the main requirement of the spaces. The typology of the *tese* from the 16th century, the Gagiandre (1568–73), derived from compound queen post trusses (compound *palladiane*, adding struts to simple *palladiane*) with closed joints and some modifications over time to increase the overall rigidity of the structures.

The roof structure of the church of San Lorenzo, built after 1592 in the Castello district in Venice, near the Arsenale, employed perhaps the widest trusses in Europe (32m). In this case the composed tie beams were supported by a central king post, crossing the collar beam (Figure 3). The structure originally supported a very large ceiling. The aspect reveals again the effort to optimize the form and reduce the cost of the structures; however, this exaggerated roof has required additional tie rods and other major repairs over time. A similar scheme of truss can be found in Augsburg, by the architect Elias Holl, who had traveled to Venice before. A totally different optimized, and successful, type of roof is the one of the Palazzo della Ragione in Padua, built around 1420 to the design by Giovanni degli Eremitani; the hall, with a span of almost 27 meters, is covered by a structure in the shape of an overturned ship hull, exactly like the Basilica of Vicenza.

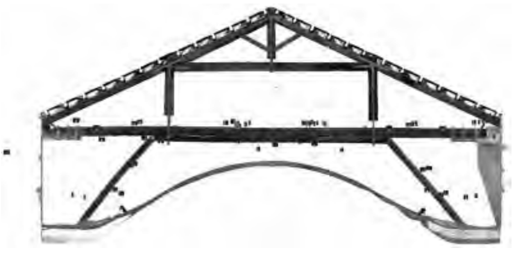

Figure 4. One of the trusses of S. Salvatore in Bologna. Point cloud section, Davide Prati and Claudio De Mattia.

The territory of the Papal State is characterized by the construction of large churches in Rome and in Bologna and similar noticeable structures. The Roman roofs show some variations of Palladian trusses (Valeriani 2003). A frequent variation to the simple *palladiane* implies the use of two trusses placed side by side (double *palladiane*) with a king post in the middle connecting them and with or without queen posts; this design can be found in all the trusses over 14 meters: S Pietro in Vaticano (24.25m), S. Paolo Fuori le Mura (24.30m), S. Maria Maggiore (17.70m), and S. Pietro in Vincoli (15.60m). The trusses in S. Sabina 14.67m) and S. Cecilia in Trastevere (14.00m) were the largest simple *palladiane*.

Figure 5. One of the trusses of S. Petronio in Bologna. Point cloud section. Authors: Tommaso Malvezzi Campeggi and Davide Prati.

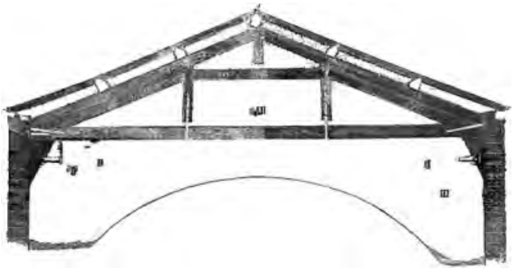

Figure 6. One of the trusses of S. Domenico in Bologna. Point cloud section. Authors: Carmine Manfredi and Davide Prati.

4 THE ROOFS IN BOLOGNA

Our knowledge of Bologna's roofs derives from research on some churches, built between the end of the 16th century and the end of the 18th century, starting with documentary investigation and laser scanner survey and ending with structural numerical analysis. The long span truss types considered in this paper all have spans over 14 meters. All the structures recall the scheme of the Palladian truss, with king post and queen posts. The fact that all the tie beams avoided the load of the ceiling was clearly evidenced by the survey, where all the joints are open; many metal straps in the roofs were found in bad conditions or already substituted – not always properly – showing consistent displacement and rotation of the king posts over time. In Bologna there is no evidence of crossing elements, as in S. Lorenzo or in the roof of S. Paolo Fuori le Mura in Rome, where the truss was quoted by Rondelet as one of the most remarkable Italian roof schemes. Besides, there is no evidence of double *palladiane* as reported by Valeriani in her survey of Roman churches. In contrast, there are some interesting variations of *palladiane*.

The trusses of S. Salvatore Maggiore (1605–23), with a span of approximately 18 meters, possibly designed by the architect Mazenta, demonstrate a certain elegance and simplicity reminiscent of the Palladian truss, except for the fact that the tie beam is supported by a *cavalletto*, formed by a beam connected to the lateral walls through struts (Figure 4). The rafters are split into two parts on each side.

Two other roofs follow the same scheme, with variations. In the case the 35 trusses of the central nave of the huge church of S. Petronio, erected around 1650 with a span of approximately 19 meters (Figure 5), the builders were still struggling with the bending of the composed tie beam which is supported by masonry vaults; we presume that this solution occurred later, when the architects observed intolerable deformations and decided that loading the vaults was an acceptable solution. Using the vaults as supporting elements is perhaps incomprehensible for us, at least without calculations. However, experience has proved that a moderate increase in the compression of the vault did not necessarily bring instability; on the contrary, it may possibly have helped center the line of thrust, placing the supports in correspondence with the haunches of the vaults. This solution is recurrent in the region of Bologna, where it was evidently well accepted. In some trusses of the roof of S. Petronio the tie beam touches the vault or is leaning on it, although the vault presumably was built after the roof.

The trusses of the central nave of S. Domenico, erected a century later, in 1727, follow the Palladian scheme, with a span of approximately 16 meters (Figure 6). In this case the builders decided to reduce the span by means of masonry corbels. The tie beam is composed of two elements (30 × 30 cm in height). The truss was probably built erecting the collar beam and the queen posts, then placing the upper rafters on the first rafters, connecting them with a king post. A continuous rafter is present in all the trusses of the church, determining their redundancy and robustness.

Figure 7. One of the trusses of S. Pietro in Bologna. Point cloud section. Authors: Stefano Lamborghini and Davide Prati.

These three configurations in Bologna show a consolidated approach to the general design of long span trusses between 15 and 20 meters, with some variations. First, they reflect the importance of contrasting the bend of the tie beam; in the case of S. Salvatore the goal was achieved by employing supporting braces under the tie beam, thus reducing the span; this solution also helped to erect the truss. In the second case, the slenderness of the tie beam was compensated for using posts laying on the vault, which is a solution observed elsewhere in Bologna, generating a more complex structural system. In the third case, the solution was found employing homogeneous tie beams of bigger sections and large corbels for the supports. What emerges here is the search for the most effective and cost optimal solution; and is confirmed by the fact that trusses were conceived to simplify the construction process, considering that each element had to be lifted separately, in relation to the dimensions and the height of the walls. Finally, they confirm the differences between long span configurations and classic Italian trusses.

An almost unique model, different to the previous schemes, and not present in Veneto or Rome, is the one conceived for the roofing of the cathedral of San Pietro in Bologna, around 1610 (Lamborghini et al. 2015). It is a series of 18 trusses, with a span of 24 meters, among the largest in Europe for a church (Figure 7). The trusses consist of a compressed arch structure that acts as a curved collar beam and is connected to the central king post, without touching the composed tie beam. It is difficult to frame these elegant trusses typologically. Quoting Palladio's presentation of bridges in the Four Books, they certainly represent an invention. To follow the categories in the literature, it is necessary to refer to them as "compound trusses" or "arched trusses", demonstrating the ability of the architects and local carpenters to optimize the behaviour of the elements under construction.

The configuration of the trusses in S. Pietro is similar to that depicted by Giuliano da Sangallo, architect and military engineer, some decades earlier. Giuliano da Sangallo, son of a woodworker and uncle of Antonio da Sangallo, was in the city a few decades before to survey the medieval plan of the church. At the time of Sangallo the city of Florence was building the roof of the Sala dei Cinquecento – built in 1497 by the architect Cronaca and restored by Vasari in 1550 – employing a compound truss with a span of 23 meters (*capriata sangallesca*). It is also possible that the concept of the truss in Bologna derived from the architect Domenico Tibaldi (1541–83); his brother Pellegrino (1527–96) was educated in the city and sketched some trusses. Research still needs to be done to find connections between the design of all these trusses.

Another similar, albeit more complex, configuration can be found in the trusses of the Farnese theater in Parma, erected a few years earlier, and, two centuries later in Emy's models in the *Traité de l'art de la charpenterie*. The structures are the result of an invention that is strongly connected to building expertise and linked to military building techniques, used for bridges. The presence of a *cavalletto* under the composed tie beam, the arched conformation of the collar beam and the organization of the struts derives largely from the construction process and improves the overall rigidity of the structure.

5 FROM THE 18TH TO EARLY 19TH CENTURIES

Towards the end of the 18th century technical achievements led to an increasingly intensive use of steel, especially in European countries with an industrial vocation. While timber roofs were still being built in Italy, in other countries such as England, France or Germany new metal or mixed structures started to be conceived for bridges, winter gardens, exhibition halls, railway stations, or factories. Timber roofs with large spans lost their importance in favor of new materials and building techniques. At the same time, the development of Building Science produced "a separation between theoretical and practical commitment, contributing to disintegrate the unity of traditional culture, but also to mobilize the repertoire of methods and forms inherited from antiquity" (Benevolo 1960).

The order of studies of the *Ecole Polytechnique*, prepared by Monge and established between 1794 and 1795, was based on mathematics and physics. Theory and practice started to be distinct aspects of building construction and a certain dualism was established between engineers and architects. On the one hand, the technological evolution proposed new materials and techniques, asking science to develop theories to verify the safety of its products. On the other hand, the modeling of reality brought about by these theories led to the search for simplified technical solutions, which constituted their application. Trusses (*capriate*, from the Latin *capra*, but also from the French *charpente*), therefore, offered an immediate and promising field of study.

European manuals started to spread the technical knowledge that was acquired through the remarkable structures already built. They arrived in Italy with some delay: *Traité theorique et pratique de l'Art de Bâtir* by Jean Baptiste Rondelet, published between 1802 and 1817, a total of 10 books, was translated into Italian only in 1832; Gustav Adolf Breymann's *Allgemeine bau Constructions Lehre* (1849) was published in Italian only in 1885.

Before the arrival of these manuals, Italian architectural knowledge in the early 19th century was enriched by a fascinating text, which summarized the state-of-the-art way in which timber was employed until that time, without resorting to mathematical formulas. The manual, *Dell'arte pratica del carpentiere*, was printed in 1826 by the Lombard publisher Vallardi and written by architects Felice Pizzagalli and Giulio Aluisetti, pupils of Carlo Amati at the School of Architecture of the Academy of Fine Arts in Milan. This was the outcome of a context closely related to the French and German building cultures, even if positioned outside the Polytechnic Schools. The text described the various ways of composing the roofs of buildings – perhaps the first in Italy dedicated to this subject in a systematic and encyclopedic way – with extensive references to the most famous European buildings and publications, such as that of Rondelet. The reference for this Italian work is given by the collection *Plans, Coupes et elevations de diverses produtions De l'Art de Charpente*, by Karl Krafft printed in Paris in 1805. Krafft's cornerstones were, in addition to Delorme's manual, *L'art de charpenterie* by Mathurin Jousse, printed in 1702, and the *Traité de charpenterie et des bois de toutes especies* by M. Mathias Mesange, from 1753. Krafft did not mention the Hassenfratz method of calculation carried out starting from 1788 on behalf of the *Academie de France* and Monge; methods that would be mentioned instead by Cavalieri San Bertolo in his manual. This aspect is significant because it testifies to the differentiation between the art of building present in the Academies and the Theory of Structures that was gaining importance in the Engineering Schools. By the end of the 18th century Italian architects and engineers were looking outside the boundaries of their country.

Like Palladio's manual, Pizzagalli and Aluisetti's book distinguishes between Italian-style and European roofs. The first Italian system consists of "lowered trusses with tie beams" (*sistema de'cavalletti ribassati*). Among the *cavalletti* composed of three posts they quote some examples in Rome, notable for their lightness, simplicity, solidity, and precise execution (Figure 8): the roofs of the church of San Paolo Fuori le Mura, the Argentine and Tordinona theaters. Among the largest Italian *capriate*, up to five posts, the authors quoted the church of S. Fedele in Milan, the warehouse of Subsistence in Turin, the trusses of La Scala theater in Milan and the structures of the Farnese theatre in Parma. While the roof of La Scala was criticized for the problems caused by the slenderness of the elements and the weakness of the joints, the trusses of the Farnese theater was considered "a model of art for its successful composition and for its solidity; worthy of reflection is the device of the three orders of braces (*saette*) arranged according to an arch that support the armrests (*bracciuoli*) in a single tie rod (*tirante*), distributing the balanced weight". The solution of the Farnese theater is therefore considered one of a kind. No roofs from Veneto or Bologna are reported, regardless of their importance. Nonetheless, the scheme of the trusses of S. Pietro in Bologna, with the arch shape, clearly reflects the principle behind the roof of Farnese's theatre. The tables of the manual are interspersed with "warnings", deduced from the practice of construction. After presenting the German roofs, the authors mention the *cavalletti* of the Moscow Exercise Room. They are examples of roofs whose notoriety derived from the manuals by Krafft and Rondelet and which would be echoed in the *Traité de l'art del la charpenterie* (1837–41) by A.R. Emy with the experiments of bent and pressed wood (Émy 1841).

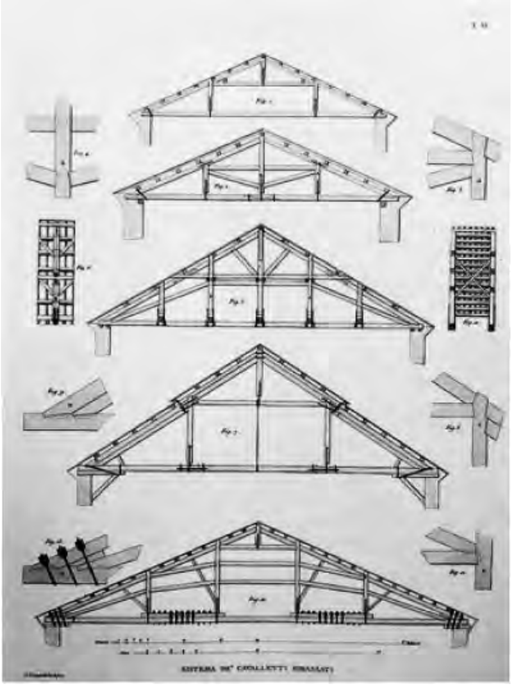

Figure 8. Pizzagalli e Aluisetti, *Sistema de' cavalletti ribassati*.

The European examples had become the standard for wood construction in Europe. Another notable roof is that for the Potsdam riding hall, re-built by Gilly. Of the notable trusses, no calculation or geometric schemes are shown, but only scale drawings, ordered by complexity and according to the geographical region and their span. The authors celebrate the work of the carpenter Lodovico Valentini for his contribution to the coverage of the Santuario degli Oblati. Special chapters are dedicated to hardware; and the dimensions of the circular section for the tie rods are also indicated (Figure 2).

In the same years, a manual was printed in Italy which suggests interest in calculation theory and verification of the elements of the *capriate* within an engineering approach, exactly the opposite of Pizzagalli and Aluisetti. The text is by Nicola Cavalieri San Bertolo, Institutions of Static and Hydraulic Architecture, printed in Bologna in 1831, then reissued in Mantua in 1833 and again in 1851. The manual is particularly interesting because the author is aware of the technological developments in France; he also works for the Papal State as a superior engineer in the department of waters and roads and is professor of architecture and statics at the School of Papal Engineers in Rome. The approach to the knowledge of trusses is classificatory, and a simplified method of analytical verification is proposed. It is effectively the first time, two centuries after Baldi, that a scientific approach is considered for the design of timber roofs. The year of publication of the book by Cavalieri San Bertolo is that of the presentation of the Polonceau truss, a successful structure in Europe that combines the elements with the material for its best characteristics: timber used in the struts to withstand bending, cast iron for the compressed elements and iron for the elements subjected to tension. The origin is military, like many other roof solutions in subsequent years.

In this book, the examples in Bologna and Parma were not taken into consideration, as they did not reflect a simple static scheme to be described in scientific terms. On the contrary, the development of the theories on bridges and trusses is reflected in the study of timber trusses, feeling the need to overcome the empirical approach, stimulate the interest of young engineers and optimize the use of materials. Since 1850, all applied mechanics manuals have a chapter on the design of reticular beams.

An important role in the development of studies on statically indeterminate structures, the former *incavallature*, is finally depicted by the theory of the continuous beam. However, it does not find application because it is too complicated and expensive in terms of calculation, leaving space for geometric methods, including the one proposed by the mathematician Luigi Cremona. Military Engineers (Menabrea 1858; Sachero 1864; Caveglia 1876) resumed their studies on the mechanics of Bresse and applied them to the roofs of military buildings such as warehouses, sheds, horse riding or armories (Zamperini 2015). As far as we know, the term *capriata* appears for the first time in 1879 in a paper by Cesare Ceradini, where the stresses in the trusses were calculated considering bending moment due to a uniformly distributed load on the rafters (Ceradini 1879) and employing the studies on graphic statics by Cremona. It can therefore be suggested that the term *capriate* is a new scientific term linked to advances in the development of analytical or geometric solution techniques for structures, and to that specific type of truss, which was precisely the Italian truss. From that time, the term *capriata* is used more and more, as all trusses thereafter will be calculated.

A defining example of the change in the paradigm concerning large span roof structures is given by the "renovation of the threatening ruin roof" of the Theater Farnese in Parma, represented in Aluisetti's manual as the best achievement in truss construction before the 19th century. The renovation work, described in the *Giornale dell'Ingegnere*, was carried out in 1868 by the engineers Giovanni Savoja under the guidance of engineer Francesco Lucca, head of the Milan State Department. The new scheme can be described as the fusion or union of three composite trusses, introducing new metal connections and tie rods: "In the encounters of the various beams making up the cross, both with each other and with the counter-chain and with the underlays, special cast iron boxes were used, from which iron rods branch off which can be lengthened and shortened by means of similar screws to regulate their connection with the chain, with the struts and with the king post and thus form a single system." The structures were reassembled using 2/3 of the previous oak and larch wood, suitably sawn to eliminate the damaged parts. The structural scheme erased all the previous practical principles.

6 CONCLUSIONS

This article highlighted through a brief analysis of some notable manuals and buildings, in particular the area of Bologna, the different ways of conceiving timber structures in Italy between the 16th and 18th centuries and the development of scientific theories.

Under the main schemes of the Italian truss and *palladiane* many variations were observed. Until the early 19th century, the safety of these structures, both in terms of resistance and balance, was entrusted to experience (Barbisan & Laner 2000). The quality of the carvings and hardware completing the connections between the elements ensured ductility and maintained a certain level of safety with respect to relative movements; stability was favored by the correct installation process, placing the elements according to a specified assembly sequence. The trusses were also conceived as defenses against the overturning of the perimeter walls; the longitudinal connection between the trestles was instead generally entrusted to the secondary reinforcement of the roof. Another assurance of safety and durability was the continuous maintenance of the roof, conceived as a unitary system.

The 19th century dramatically changed the schemes of the trusses, which started to be calculated as reticular beams. In trying to preserve old structures, we should be aware of their conception and behavior. Today our interventions often cause further damage by trying to apply structural principles to elements that were conceived differently.

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History of Construction Cultures – Mascarenhas-Mateus & Paula Pires (eds)

Design-Fabricate-Assemble-Marvel – 18th and early 19th century bridge models in the construction process

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ABSTRACT: One of the earliest reports on the use of a model in the technical design process surfaces in a town council document concerning a bridge project over the river Elbe in Meissen Germany in the year of 1657. The council noted in being possession of an old and a new wooden model of the main span of its covered bridge, one being “*built by a good master and appearing to be artistic*”. What exactly was its function and how did it serve the construction process? The Meissen models and others like them are more than just a superficial presentation, they prove that the structure can be assembled, they show the designer flaws and weak spots in the design and allow him to iron them out before real construction and real consequences start. They also carry his reputation and allow us to recreate the erection of some of the most spectacular gravity defying and now lost structures. This paper will summarize the information known and briefly describe in those 17th to early 19th century models to document the current state of historical research.

1 INTRODUCTION

It is still possible today to visit some 360 historic wooden covered bridges in Europe in their natural surroundings, the oldest dating back to the 16th century. As their designers and builders began to consider ever longer free spans, traditional tried and trusted solutions needed to be replaced with innovative, complicated and practical systems that had never been built before. Building a bridge was never an easy undertaking, most importantly the designer had to guarantee the bridge’s stability and reliability during its working life, but also had to keep costs down and make sure the inherently dangerous assembly operation would actually work. Structural models were employed to help those involved in the building process to transition between a design idea and assembling the real thing.

2 EARLIEST MODELS

The earliest wooden bridge construction models have not survived in their physical forms. Probably hundreds of models were built over the centuries but these were never documented in any form thus making it impossible to form even the wildest speculation about number, size or level of detailing. The proven usefulness of later models leads one to believe that models existed well before those actually known.

Wendelin Schildknecht’s treatise *Harmonia in fortalitiss construendis …* (Schildknacht 1652, 423 [schematic illustration] and 428), published in 1652, identifies a five-metre-long bridge model. Schildknecht’s written description of the model makes it clear that this was a structural model, designed for testing specific joints in a beam. The main pieces were only 1 1/3 of an inch thick. The model was supported only at both ends leaving an almost five metre free span and then stress-tested by four burley men who climbed on to it together. Schildknecht, (a well fed man as he described himself) climbed aboard as number five and the bridge took the weight. If such a weak structure could take the weight of five men, then think what a real bridge could support, he argued. This is probably one of the oldest, if not the oldest, known wooden construction models of a wooden bridge.

Leonhard Christoph Sturm described several models in his treatise *Hang-oder Sprengwerken …* (Sturm 1713, 40, Taf. IX and X) published in 1713. Their purpose is primarily to understand the stability of the full-sized structure by building a scaled model, then load test it and from that calculate the expected full-size loading. The first model is described as $^1/_4$ inch squared with a ratio of model load to full-size of 2,304. Though not directly stated, presumably the $^1/_4$ inch is the ratio to one foot and the square is the loading multiplication factor, which can be deduced from the numbers given ($^1/_4$ inch:12 inches = 1:48 and $48^2 = 2{,}304$, further analysis and a historical overview of structural analysis using scaled models can be found in Holzer (Holzer 2010).

At a scale of 1:48, the 66 Foot (= *c*. 18–20 m) span at full-size makes the model quite small giving it a 42 cm free span. Sturm states that the minimum applied load of 100 Pounds (= *c*. 50 kg) to the model will result in the bridge being able to carry 276480 Pounds. If the

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multiplication factor is 2304, then the sums simply do not add up. Either the minimum load on the model should be 120 Pounds (= *c.* 60 kg) or the full-size bridge can carry only 230,400 Pounds. There is no mention of any other use for the model.

Sturm addresses accusations that what works in a demonstration (model) may not necessarily work in practice and that things working on a small scale do not always work on a larger one with two statements. Firstly, he states that demonstrations do work in reality when the correct materials are used and the workmanship is sufficiently accurate, and secondly, that scaling works when everything is correctly proportioned. He then proceeds to reveal that his models are not just accurate representations of the wood- and ironwork, but that in scaling up the joints, these become not just as accurate, but even more accurate when built at full-size. Finally, he argues that the many suspended-post structures already built support his statements from which we can deduce that models were made in advance to "prove" the structural stability of these structures.

Sturm continues with another model of his own design. This time the scale is 1/4 inch:1 foot 4 inches (= 1:64) the square of which is 4,096, but attributed a lower (safer or simpler?) value of 4,000. Again, the model is used primarily for testing the structural stability and carried 110 pounds of lead weights, thus, he argued, the full-size span will carry 4,000 hundredweight.

Sturm's third model is a much larger scale for a much larger bridge over the River Elbe. The trusses are designed to span 154 feet (c. 40–46 m) and if the 1/2 inch sized model wood is in scale to one foot (not actually stated) then at a scale of 1:24 the model was around 2 m long. Instead of scaled mortice and tenon joints connecting the elements, they were pinned together.

Finally, Sturm reports on a model exhibited in Paris designed by Claude Perrault (1613–1688) constructed at some time in the latter half of the 17th century. The model of a proposed bridge over the river Seine at Sèvres, near Paris with a clear span of 30 Toises (1T = 1.949 m = 58.47 m) is described by Sturm as having a clear span of 14 feet, the full-size span being 224 feet, and built at a scale of 3/3 inch to one foot giving the model a scale of 1:16. To demonstrate its stability, a six foot (1.6 m) high wall was erected on the 3.5–4 m model which astounded onlookers. Conflicting reports of the design of the bridge/model in various 18th century treatises suggest that two alternative designs abounded (Perrault 1700, Gallon 1735, Holzer 2010), it is not clear which of the two was actually constructed as the model.

There is no proof that any data other than load testing was collected from these models although the fact that each model was actually built is in itself a demonstration or partial-demonstration of the design concept and its physical assembly. The fact that pins were used (in at least one model) instead of the real joints is a deviation from the "accuracy" that Sturm declared as a prerequisite for using models to calculate the load. Sturm's statement that the scaled up real joint in the full-size bridge is more accurate, i.e. "better" than the model obviously does not apply when pins replace certain kinds of joints in a model, simply because the pins behavior is quite different from a mortice and tenon or a lap joint. Without doubt, these models do demonstrate a certain level of feasibility, whilst also leaving many construction questions open.

3 THE OLDEST EXISTING MODELS

Erich Deil was the first to research several wooden models found in Meissen's town museum in his PhD thesis published in 1916 (Deil 1916). The largest model (Inv. No. 330) is 1.8 m long at its base and has a free span of 1.48 m giving it a scale of approximately 1:28.7 (Figure 1). It is clearly a representation of the largest free span (42.5 m) of the multispan bridge over the River Elbe at the town of Meissen in Saxony, Germany built between 1657 and 1664. The town council recorded that there are two models (an old and a new one) of the largest span at the town hall. One model had been built by "a master carpenter of repute, appearing to be proper, but will need to be improved upon, so that the structure won't vibrate under heavy loads" (Deil 1916, 24).

By 1657, a master Eckhardt had made another model of the 42.5 m span, which Deil reports was used in 1664 to finish the span. A year later the span was pushed out of position over the river breaking an oak crossbeam. It then collapsed completely in June after just 28 weeks of service. The remains were fished out of the river and reassembled together with 53 new trunks and then re-erected. The bridge was completed by August of 1667.

The span was a world record holder for the length of its free span (probably unknown at the time) and a magnate for those interested in the contemporary construction of bridges. The design appeared in two treatises (Vogel 1708; Leupold & Zunckel 1726), which depicted the unique double layer truss system with an inner layer based on a queen-post solution clearly designed to carry the weight of the bridge to the abutments.

The outer frame consisted of posts, lower and upper chords and two rails. The upper chords support the roof and transmit their loads (side covering and roof) to the inner truss. All this is identical to the model, but the model also contains a third queen-post truss frame inside the bridge.

Deil also quotes the Articles of the Carpenters Guild from 1651 found in the History Society of the Town of Meissen, which stated that: "To become a master, it is necessary to fabricate a difficult roof frame, also deconstruct it, he should construct a bridge span using small wood (as a model) whilst at the same time being under the scrutiny of three experienced skilled craftsmen and members of the town's building office."

By 1723, the 42.5 m span had to be repaired, which involved the town council's master carpenter Martin

Figure 1. Model of the largest span which stood from 1664 to 1757, Town Museum Meissen, Inv. No. 330 (Photo: author).

Pfitzner. He had made a model of the large span as part of his master craftsman's exam sometime earlier. Jakob Leupold criticised this repair in his treatise *Theatrum pontificale* (Leupold & Zunckel 1726) three years later explaining that the original design had just two truss layers and that the third just loaded the already overloaded bridge still further. It would thus appear the model with its three layers of trusses is not the original model by master Eckhardt made in around 1657 but rather the work of Martin Pfitzner some 70 years later.

Leupold mentions in his treatise that an Andrä Gärtner (1654–1727) is the "Electorate of Saxony's master modeller" who designed a wooden bridge with a 200 ell (Dresdener Elle) free span and built a flawless model version of it. In the early 17th century, one Dresdener Elle equalled 0.664 m, making the bridge c. 133 m long. There is no description of the model or to what scale it was constructed. The most interesting aspect of this information is that there is an official post of model maker (possibly better translated as instrument maker) and that Gärtner made bridge models for the Elector of Saxony and his scientific collection.

In Gärtner's curriculum vitae published around the time of his death, the model is referred to as just 100 ells long (Marperger 1724). It still requires determining whether this and other models are in storage somewhere. An inventory of the model collection together with the Royal Cabinet of Mathematical and Physical Instruments, Dresden published in 1835 by Wilhelm Gotthelf Lohrmann reveals that: "Item 56, a model of one span of the former bridge at Meissen (Nr. 22)" was part of the collection (Lohrmann 1835, 75). In 1835, the Meissner bridge's last wooden spans were of the Wiebeking below-deck wooden arch design and were erected in 1814. The "former bridge" could refer to the 1765 spans at Meissen, in either case there would be no link to Gärtner.

4 MODELS AROUND 1750 AND LATER

In addition to the treatise, the early eighteenth century saw a number of practical men experimenting with radical ideas, either in length of span or the joining of timbers. William Etheridge had been working on the concept of a web for trusses made by "weaving" multiple tangents to a circle together (Caston 2015). The origin of the idea is not clear. It first surfaces in the design of a wooden *Westminster Bridge* in London attributed to his then employer James King in 1737 but may also have been influenced by Etheridge himself. After King's death, the idea appears in the design for the *Old Walton Bridge* over the river Thames near London in 1747, then again two years later in the design of the *Mathematical Bridge* over the river Cam in Cambridge in 1749. A model of the bridge, presumed to be 18th century still survives in Queens' College, Cambridge.

The 1:16 scaled model is accurate in its documentation of the "weaving" of the web tangents (on just one side) and "L"-shaped metal brackets but deviates by the use of a solid web on the other side and the usage of screw-eyes in the joints plus other small details. Clearly, this model is not intended for load testing with accurate scaled down components expected to act as the full-size bridge but rather as a demonstration model.

At least eight historic wooden bridge models are known to exist or have existed in Switzerland (Schäfer & Holzer 2018).

In his research into the famous master builder Grubenmann family, Joseph Killer collected data on several models known to have been constructed by them or that he attributes to them. The oldest model, which Killer dates to between 1745 and 1755 (Killer 1941, 22), is *c*. 270 cm long and held by the Grubenmann Museum in Teufen, Canton Appenzell Ausserrhoden, Switzerland.

Jasmin Schäfer and Stefan Holzer calculated that the model's free span of 212 cm taken with Killer's stated 30 m free span at full size would give the model a scale of approximately 1: 14 (Schäfer & Holzer 2018). It is unclear which actual bridge is represented by the model. It could be just a design study. The polygon arch struts are unusually slender and the overall cross section of the struts added together is small, even appearing smaller than the arched tie-beam lower chord, which is unusual and possibly near the limit of functioning as a compression arch. The size of the model would lend itself to simple load testing with everyday building materials.

The most well published reference to the use of a wooden model in the design of a Swiss wooden trussed bridge is Killer's (Killer 1998) reported anecdote concerning the Rhine bridge in Schaffhausen built in 1755/58 by Hans-Ulrich Grubenmann (1709–1783). The first meeting with the city council in Schaffhausen in 1755 did not go to well. After preliminary talks, Grubenmann did not return on the second day, complaining that they would not listen to his advice. Later in the year, he would return with a wooden model onto which he climbed to dramatically demonstrate the load carrying capacity. In October, he was awarded a contract to build a design consisting of two unequal spans (52.1 m and 58.8 m) and slightly kinked to make use of a stone pier in the river.

A large historical model of the two-span design on display at the Museum zu Allerheiligen in Schaffhausen is believed to be the Grubenmann original. The design is very similar to one of two historical drawings held in the Museum's archives.

The second historical drawing delineated in the same fashion with a single span of 119 m in the archives is considered to be the initial single-span design that was rejected by the city council. Presumably, Grubenmann climbed up on a model version of that and not the final design. Amman (Amman 1983) reports that the model was transported to Schaffhausen in pieces in a rucksack for the demonstration, but there is no record of what happened to this model afterwards. If the single-span model was the same size as the two-span design in the museum it would have been constructed at a scale of approximately 1:26 and been approximately 4.5 m long.

Based on the museum drawing for the single-span design, students from Neubrandenburg University of Applied Sciences in Germany completed a larger 1:20 scale wooden model in 2017 to experiment with how the assembly might have worked (Figure 2). The 6 m long model took 6,000 work hours to build with the help of 24 students in small and large groups working on and off for over 12 years. During the construction, it soon became apparent where the design restricted the assembly or was not clear enough in the drawing or had to be interpreted to work. Whilst the weight of the model wood is several hundred times lighter than at full scale and consequently lifting with our dexterous limbs is easier than with machines and their movement restrictions, just the simple fact that gravity acted on every piece made working with the model far more realistic than in the virtual environment in CAD (which we also tried). This also demonstrated which pieces did not fit and in what order pieces needed assembling.

Our model used metal bolts where possible even if fitting the long iron rods through the multiple struts at the ends would have meant disassembling the whole model then drilling individual pieces, all at the correct angle. Due to time constraints we abandoned this, which is a deviation from the original and affects the structural performance.

Other historical models of Hans-Ulrich Grubenmann's bridges include one each by Schaffhausen and Wettingen in the Ecole des ponts et chaussées, Rue de Grenelle, Paris (Ebel 1798).

The Central Museum for Railways in the Russian Federation, St. Petersburg has a 4.98 m long, 53 cm wide and 61 cm high model of a design proposal for a single span over the River Neva by a Swiss carpenter called "Aldon". The model was made in 1762 and at a scale of 1:60, the full-size version would have spanned 298 m (Kahlow 2020). The design was never realised.

In 1764, Hans-Ulrich Grubenmann was invited to tender for a bridge over the River Limmat in Wettingen. The final contract required him to build the bridge and construct a model to explain the design. The model was thought to be lost but turned up years later in the Canton of Aargau's building department. The model, at a scale of 1:40, differs from the bridge as realised in that it has eleven suspended posts instead of nine as actually built (Killer 1998, 42–46).

A second model (Inv. No. 331) stored in the Town Museum in Meissen can be clearly attributed to its span designer Christian Gottlob Reuss (1716–1792) as it is marked with his name (Figure 3). Reuss was a theatre stage designer and the royal court carpenter. He probably did not actually make the model himself. He was charged by the King of Saxony in May 1763 to oversee the rebuilding of the 42.5 m main span at the

Figure 2. H.-U. Grubenmann's single span design for Schaffhausen. Model made by students, finished in 2017 (Photo: Ralf Ströde, Neubrandenburg).

Meissen bridge following its destruction in 1758. The design not only appears as a model but also in several scaled drawings in various archives.

During repairs to the bridge in 1785, Johann Gottfried Jentzsch (1759–1826) recorded the structural details in his pen-drawing "Die Meißner Brücke" which confirms the use of the Reuss design. The span was erected in 1764 during which time Reuss published a treatise on carpentry *Anweisung...* (Reuss 1764). Strangely the Meissen design is not mentioned but designs for shorter bridges clearly related to it are depicted.

The model was not just a design and/or built study but formed part of an agreement binding the builder to reproducing it full size for the real bridge. The King's building inspector Friedrich Exner, commented amongst other things that the bridge was constructed according to the "approved model" (Deil 1916, 46). The model was thus part of a formal transmission of the design into reality.

In his treatise *Brücken-Bau* published in 1766, Caspar Walter (1701–1769) reveals that he tested loading on two models that he had built himself (Walter 1766). Both models are shown in the treatise as architectural designs. The first model is reported as being 200 feet long and built at a scale of $\frac{1}{2}$ inch to a foot (1:24). Depending on which foot size is meant (the Augsburg foot measured 0.296 m), the full-size bridge would have had a clear span of around 60 m and with the model being 2.5 m long. Similarly, the second model representing a bridge 300 feet long would have been 3.7 m. The design does not rely on suspended posts but clearly displays the use of an arch with clasping radials.

5 BISHOP HERVEY'S COMPETITION

In the same year Frederick Hervey, Bishop of Derry (1730–1803) returning from his first European grand tour visited Schaffhausen and presumably realised then or sometime later that a similar design could be employed to span the River Foyle in Derry, Ireland. His interest in bridges would lead to a spate of models.

In 1770, he set off on a second European grand tour with his eldest son and the architect Michael Shanahan to collect data and make drawings. On his outward journey through Switzerland he arranged, at some stage before October, for Grubenmann‘s foreman to build a model for a proposed Foyle River bridge to cost one hundred Louis d'or's. The details of this request still need to be clarified. The original stipulation was for a single arch, and to be ready within 11 months. This would coincide with a design competition that Hervey would initiate in early 1771. Invitations to submit a design proposal for the bridge appeared in Switzerland and Germany stating a submission date on the 1st August of that year and a decision as to the winner two months later.

Figure 3. Model of the largest span which stood from 1767 to 1813, Town Museum Meissen, Inv. No. 331 (Photo: author).

In October 1771, Shanahan was summoned to Chur in the Grissons to examine the plans and where Hervey was to join him. Sometime between then and April 1772, when Hervey left to return home, the winner must have been chosen and the drawings and models packed up and made ready for transport.

The *Post und Ordinari Schaffhausner Samstag-Zeitung* reported in its 1st April 1772 issue, that Johannes Grubenmann (the younger) had been awarded the money for his plan (design) and a model. The whereabouts of this model is unknown, it was probably documented in a drawing by Shanahan entitled: *The first model of The Bridge of Derry*, but the design shown is a double, and not a single, span.

The competition received some 300 entries, probably mostly drawn plans, but including some models. At least two models were to be taken back to Derry and can be traced loosely on their journey across Europe. A report in the September issue of the Gentleman's Magazine (Unknown 1772) states that a six metre long model was dragged on a four-wheeled cart covering an average distance of six to eight miles a day by its creator Johann Konrad Altherr and two assistants. The model had been on the road for approximately five months before reaching England. It had to be in Ireland by the 22nd of November.

The report gives the full-size dimensions of the proposed bridge and some details about the model, which consisted of 11,734 single pieces and some 4,000 screws. It was made at a scale of 1:48 and based on the design of the bridge at Schaffhausen. The estimated building cost is £19,000.

Nicola Navone's research into Altherr revealed that he continued to London with the model, presented it to the king and received a reward (Navone 2003). Hervey never received the model, presumably it stayed in London and is the one stored in the Science Museum. Altherr worked together with Johann Konrad Langenegger (1749–1818) from Gais on the model, back in Switzerland they would eventually build a second one, which was taken to Vienna and presented to the Emperor.

A second model, presumably also on its way to Ireland, made it to the Hôtel d'Espagne in Paris in late October 1772, where leading French architects and engineers had a chance to study it. It was Dresden carpenter Johann Christian Clauss's design and had achieved second place in the competition.

The design appears in Armand-Rose Emy's treatise *Traité de l'art de la Charpenterie* (Emy 1841), as a double lane single span with a 300 m free span and built at a scale of 1:48, making the model over 6 m long. To celebrate the occasion, Claus had a leaflet printed, which claimed the bridge to be "the eighth wonder of the world". The model is presumed to no longer exist.

Probably the most spectacular model was Ivan Petrovich Kulibin's (1735–1818) 30 m long 10th scale of his Neva River bridge in St. Peteresburg, first brought to the attention of the wooden bridge research community by J. G. James in 1982 (James 1997). Work on it began in 1769 and it is reputed to be made from 15,250 wooden spars and planks and use 496,050 screws, 5,500 iron sleeves, and 1,000 balusters and weighing 5.6 tons in total. It took six carpenters one year to complete.

It was load tested on 27th December 1776 and carried 62 tons for one month without producing any deflection. The test served to establish the load carrying ability of the model and the results would serve for much theoretical discussion by famous structural theoreticians such as Leonard Euler and Nicolaus Fuss. Kulibin published his results 23 years later. The model was moved from the St. Petersberg Academy of Sciences to the Taurida Palace in 1793. It collapsed there in 1816.

A smaller version of it measuring 235 cm and at a scale of 1:125 is stored in the State Hermitage Museum in St. Petersberg. Presumably, this was an earlier concept model.

Recent research by Andreas Kahlow on this topic has revealed a rival bridge design by a Major José de Ribas (1749–1801). At 1/30th of the width of the river, it appears to have been built at the same size and also tested on the same day as Kulibins (Kahlow 2020). It failed the test miserably. A second much larger and modified model (at a scale of 1:20) had been built by 15th November in the same year when it was load-tested. The first test seemed successful but the parameters were heavily criticised. A second test was again unsuccessful causing doubts about the validity of scaling up models. Neither design made it to a full-size bridge.

6 EARLY NORTH AMERICAN MODELS

In 1797, Charles Wilson Peale (1741–1827) patented a design in the United States for a 118.9 m free span arched bridge over the Schuykill river in Philadelphia. The bridge was never built but the design was documented in his essay (Peale 1797), where he also mentions a model with an 80 ft. chord (24.39 m) attributing the model with a scale of 1:4.8. Peale further reported the model was displayed in a museum (of which he was the owner) in Philadelphia.

Other turn of the century models included that of Thomas Pope's "Flying Lever Bridge" exhibited in New York. Details of it are recorded in his treatise of bridge architecture (Pope 1811). The proposed full scale bridge over the East River in New York had a free span of 1,800 ft. (548 m). Pope states that the "Grand model" was built at a scale of 3/8 of an inch to 1 foot, giving it a scale ratio of 1:32. It would have been 56 ft. (17 m) long. His next stated information is however contradictory: "the length of Model of half bridge, in real measure, is nearly fifty feet". If the "half bridge" model was almost 50 ft. (15.2 m), the full length would have been almost 100 ft. (30.4 m) and the scale ratio would have been 1:18. The half bridge demonstrated the lever principle and supported ten tons. 16 examiners of the model attested to its strength, practicality of erection, durability and suitability.

The Mechanics' Magazine (London) reported in its March 23rd 1833 (Unknown 1833) issue on a model of a bridge displayed at the National Gallery of Practical Science in London. It represented a 750 ft. (228 m) "immense wooden bridge" at Terrabonne near Montreal, Canada, which actually stood for a short while but was washed out during repairs. The 1833 catalogue issued by the Gallery lists the model as object No. 27 in the lower gallery, as being deposited by Joseph Gwilt, esq and made to a scale of 10 ft. to an inch (1:120). At that scale, the model must have been 1.905 m long. The design is described as "a system of trusses, in a longitudinal direction, the feet of each being supported from the crowns of the bend arches, which were in thickness scarfed together, and thus the feet of the adjoining trusses were supported from the crown of the bent rib, immediately thereover, as in a common truss" (National 1833). Initial research into the bridge has not thus far uncovered any further information.

Finally, a model of Michael Janek's (1770–1842) proposed bridge over the Vltava River in Prague from 1832 is held in the Prague National Technical Museum (Bláha & Ebel 2005). The scale and size remain unknown.

7 CONCLUSION

It is the difference between the full size realties and those reduced or simplified in the model that define the role of the model in the building process. Whilst some argue that the abstracted model cannot simulate all possible forces on it and therefore not fully prove a real world scale-up and see this as a disadvantage, others recognise that it is exactly this abstraction that reduces unknown variable factors that could otherwise jeopardise a great idea and see this as an advantage. Between an intangible idea and a real physical structure, the model plays a vital role in understanding and simulating the spatial design, fabrication and assembly. It plays a vital role in approaching the final result, but stops short of it. This is frustrating for those who want to "prove" the intended result in advance but is inspiring for those who cannot imagine it. Models are a vital stepping stone to the realisation of spectacular projects. In the case of 18th and early 19th century wooden bridges, they are the last remaining physical manifestations of these marvellous objects or of unrealised dreams. They can still inspire and fire the imagination and remain an important link to the past.

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History of Construction Cultures – Mascarenhas-Mateus & Paula Pires (eds)

Late 18th-century innovation: The first Mediterranean purlin roof truss in German-speaking Switzerland at Embrach ZH

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ABSTRACT: Swiss architect David Vogel (1744–1808) enjoyed a thorough theoretical training compared to his compatriots. His most important commission after his education was the transversely oriented “oval” reformed church at Embrach ZH (1779–80). Vogel’s designs show distinct Italian influences from three years of studies with Winckelmann in Rome in the 1760s. He integrated these ideas into the designs for the church at Embrach, where both the architectural layout and the construction were innovative for the German-speaking part of Switzerland, including the comparatively flat roof pitch with a Mediterranean roof truss. This paper focuses on the preserved construction, which adapts the Italian standard to local conditions. The roof structure at Embrach is pioneering since the type of roof truss employed was later generally adopted in the 19th century throughout the German-speaking world for constructions with a lower roof pitch.

1 THE ARCHITECT DAVID VOGEL

1.1 *Study visit to Rome*

The architect David Vogel was born in Zurich on 12 February 1744. He originated from a family of master builders who had been passing down the craft for many generations (Zwicky 1937). He started his education in the bricklaying business of his father, Heinrich Vogel (1717–1775), but already as a young man his main interest lay more in theory and science than in practice. He belonged to the society of artists and scholars in Zurich around Johann Caspar Füssli, Salomon Gessner and Leonhard Usteri. They recommended he study under Johann Joachim Winckelmann (1717–1768) in Rome (Gubler 1974: 281), and in 1763 the nineteen-year-old Vogel set off towards the South and first travelled on his own to Northern Italy before finally arriving in Rome at the end of the year (Usteri 1778: 127).

Vogel’s three-year study visit is documented by numerous letters to his Zurich friends Füssli and Usteri and through a bundle of large-format drawings, which are kept in the manuscript collection of the Zentralbibliothek Zurich (ZBZ). Vogel probably compiled his collection in a very conscious way to bring home a repertoire of representative architectural models for later reference. In his time, training as an architect involved not only drawing one’s own surveys of buildings but also copying existing plans (Maronnie et al. 2019: 21). Therefore, it is almost impossible to determine which buildings he surveyed himself – he signed most of his plans with “D. Vogel de Zuric”. In addition to ruins from antiquity, early Christian basilicas, baroque churches, palaces and villas, three sheets from the bundle show timber roof constructions.

To the annoyance of his teacher, even in Rome Vogel’s enthusiasm was directed more towards the study of contemporary technical literature than towards architecture (Blümner 1882: 129). His interest in scientific treatises published at that time by German, Italian, French, English and Dutch architectural theorists is attested to by the catalogue of Vogel’s own collection (cf. “Verzeichniß einer Sammlung architecton. Werke v. David Vogel gesamm. Zürich, bey Salomon Frieß 1809”, ZBZ, Rara 18.1676,8). His private collection included editions of Vitruvius, Palladio, Serlio, Vignola, Alberti, Philibert de l’Orme, Sturm and Blondel, part of which in several languages and to mention only the most famous masterpieces on architectural theory in his possession. He also owned numerous treatises on bridge building and hydraulic engineering published up to the end of the 18th century. The works by Robert Pitrou (1756), Johann Esaias Silberschlag (1772), Henri Gautier (1765), Caspar Walter (1766), Lucas Voch (1776, 1780), Carl Christian Schramm (1735), Bernard de Bélidor (1740) and Carl Friedrich Richter (1765) are worth mentioning. In the context of roof framing studies, the carpentry treatises by Jost Heimburger (1729), Matthias Mésange (1753), Johann Jacob Schübler (1731), Leonhard Christoph Sturm (1726), Caspar Walter (1769), Johann Wilhelm (1649) and Christian Gottlob Reuß (1764) are of particular interest. More than 300 books prove that the architect was well informed about contemporary construction techniques at home and abroad.

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1.2 *Works*

After returning from Rome in 1766 and passing the examination for the master craftsman's certificate, Vogel's contacts encouraged him to establish himself in Zurich. However, he did not achieve great success in practical construction work: only five projects were realized according to his plans and under his direction. In Embrach (1779–1780), Vogel built the first neoclassical church in German-speaking Switzerland, in contrast with the still prevailing late Baroque tradition (Carl 1979: 207). Shortly before, Vogel had already received his first commission: a new parsonage for the parish of Rorbas, not far away from his main job. In 1781, Vogel submitted design plans for the Helmhaus in Zurich, but these were never executed. His participation is also mentioned in the new construction of the Hirschengraben staircase to connect to the Seilergraben in Zurich around 1790 (Carl 1979: 208). In 1794, he supplied plans – implemented a short while later – for the extension of the north tower of the parish church of Winterthur. His project involved raising the church to a height that would also bring the exterior appearance into line with the baroque design of the existing south tower.

In the mid-1790s, Vogel moved to Paris for a few years and witnessed the aftermath of the revolution. This stay shaped his following works. Several of Vogel's political writings from this period are also preserved (cf. Vogel 1798). After his return to Switzerland, the committed republican became politically active and worked for the Helvetic government as head of the building department (Zwicky 1937: 41). In 1805, he took over the supervision of watercourses and dam maintenance, since his superiors deemed that "no use can be made of the architectural services offered by Mr David Vogel" (government decision of 1805, StAZH, MM 1.11 RRB 1805/0096). Presumably also in this context, Vogel was commissioned one year later by the building department to examine the competition designs for the new Rhine bridge to be built near Eglisau, for which he also submitted plans. A few years later, he died in Zurich on 10 December 1808 at the age of 64.

Vogel was known to his contemporaries as an architect "whose great theoretical knowledge combined with the meagreness of his practical experience, and the merits and shortcomings of his personal character, to produce the strangest of contrasts (...) His curiosity was immense, his narcissism not much less" (Füssli 1806: 4022).

2 THE REFORMED CHURCH AT EMBRACH

2.1 *History of the building*

The present church of Embrach, completed in 1780, replaced the Gothic predecessor which had been severely damaged by an earthquake in the winter of 1777. The bailiff of Embrach was concerned, and demanded that someone "who had experience in the art of building should take a closer look" at the dangerous situation (Thomann 1927: 83–84). Therefore, David Vogel was called to Embrach as an expert consultant. He presented a proposal for the protective measures to be carried out to the building. However, only two days after underpinning of the foundations had begun, the entire tower including the choir collapsed and damaged parts of the nave (Baer 1980: 4). As a result of this incident, the Commission decided at the end of 1778 to rebuild the entire church, and called for project proposals to be submitted (Thomann 1927: 89).

Figure 1. Exterior of the reformed church at Embrach, looking west (Schäfer 2019).

Thereupon, "architect David Vogel, master bricklayer Bluntschli and master bricklayer Hafner of Winterthur drew up plans, from which the draft of the first was selected on 24 April [1779] and the entire project was signed on 10 June" (Vogel 1845: 173). According to the decision of the commission, Vogel's design "would be the most durable building because of its configuration", although "no such building has so far been found in our country" (Thomann 1927: 90).

2.2 *Architecture*

The ground plan of the church at Embrach consists of a square that is closed off by semi-circular apses in the east and west, thereby creating the impression of an oval building. The south side is marked by a pediment which, together with the front tower, dominates the main façade and announces the transverse orientation of the interior (Figure 1). The plain interior with a width of 13.7 m and a length of 25.5 m and flat ceiling is lit by high rectangular windows. The pulpit on the north side is located opposite the main entrance. In front of it is the baptismal font. The pews of the hall and the cantilevered galleries are arranged in a U-shape around the pulpit. Neo-classical stylistic features characterize both the external appearance with its temple-like front and interior of the building. When the building was completed, "the beautiful symmetric church, one of the most graceful in the canton"

Figure 2. Main façade of an oval church building. Design plan by David Vogel around 1780 (StAZH, PLAN R 310).

was acclaimed (Erni 1820: 223). “The great taste that prevails in the whole building, both inside and out, testifies that the master builder, Mr David Vogel of Zurich, was especially educated in Rome and Naples” (Nät 1802: 219–220).

The reformed church at Embrach is the only religious building by David Vogel to be executed. However, the numerous designs for churches he produced illustrate how intensively Vogel occupied himself with the architectural requirements of Protestant liturgy. His designs recall the plans for transversal churches published in 1718 by Leonhard Christoph Sturm. In addition to trapezoidal ground plans, oval ones in particular seemed to fulfil his ideals of a reformed church building. A drawing with an elevation of a main façade which contains three variants of the tower end (Figure 2) may be considered as a draft design for the church at Embrach. The biapsidal building in early neo-classical style has a pedimented front and closely resembles the completed building.

Vogel had already paid particular attention to oval ground plans in Rome as testified by some of his architectural surveys, and the Baroque oval churches of Sant’Anna dei Palafrenieri (Giacomo da Vignola, 1583) and especially the church of Sant’Andrea al Quirinale (Giovanni Lorenzo Bernini 1670) may have contributed to inspiring the church in Embrach. Until then, the oval shape for religious buildings in Switzerland had been common only in the French-speaking West, which was influenced by Huguenot temple architecture. The reformed church buildings of Chêne-Pâquier (1667), Oron-la-Ville (1678) and Chêne-Bougeries (1756) could be mentioned here.

2.3 *Roof construction*

With a roof pitch of 33°, the construction is relatively flat in comparison to the contemporary baroque roofs of the German-speaking part of Switzerland. The construction of the roof is similar to the layout of a Mediterranean or Italian roof truss (Figure 3).

This system existed in the Mediterranean region as far back as antiquity. The purlins, which support the common rafters and the roof covering, rest on triangular principal trusses consisting of two principal rafters and a tie-beam. Depending on the span, there are variants in which the tie-beam is additionally suspended by one or more tension posts, and the construction is stiffened by rafters and a collar beam. Diagonally arranged raking braces between the king post and the principal rafters are typically used.

The roof structure of the reformed church at Embrach was designed according to this model. It consists of five principal trusses above the nave, which are arranged at an average distance of 3 m, with two secondary trusses in between each pair of principals. A continuous tie-beam, two inclined principal rafters and a king post form the principal trusses (Figure 4).

The lower ends of the principal rafters are tenoned directly into the 16 m long tie-beam. At the upper end they are attached to the king post with a small abutting joint and an additional tenon. The king post carries a ridge purlin at its upper end. At about half the height of the construction, a kind of two-part straining beam is tenoned between the king post and the principal rafters. Similar to the raking braces of a conventional purlin roof truss, this contributes to stabilizing the principal rafters. Extended by means of a nogging piece of wood, the straining beam joins the common rafter. The semi-circular hipped roof ends on both sides employ three principal half-trusses each, which are designed according to the same principle as the normal trusses.

On top of the tie-beams, a longitudinal girder runs along the central axis. It is attached to the king post with stirrup straps. In addition, rectangular purlins or collar plates connect the principal trusses in longitudinal direction. They are tenoned into the principal rafters at both ends. For this purpose, an inclined tenon is worked out at the joint, which runs parallel to the inclination of the principal rafter. The mortices also have this shape and partially pass through the full thickness of the beam cross-section.

To suspend the tie-beam, a hand-forged stirrup strap is inserted through the girder and attached to the king post with two bolts and square nuts (Figure 5). Small wedges in the girder prevent the iron from slipping. The girder runs the entire length of over 25 m; it consists of two pieces which are connected in the middle with a wedged Jupiter joint. In addition to the wedges, iron bolts secure the wooden connection.

Figure 3. Roof construction of the church (Schäfer 2019).

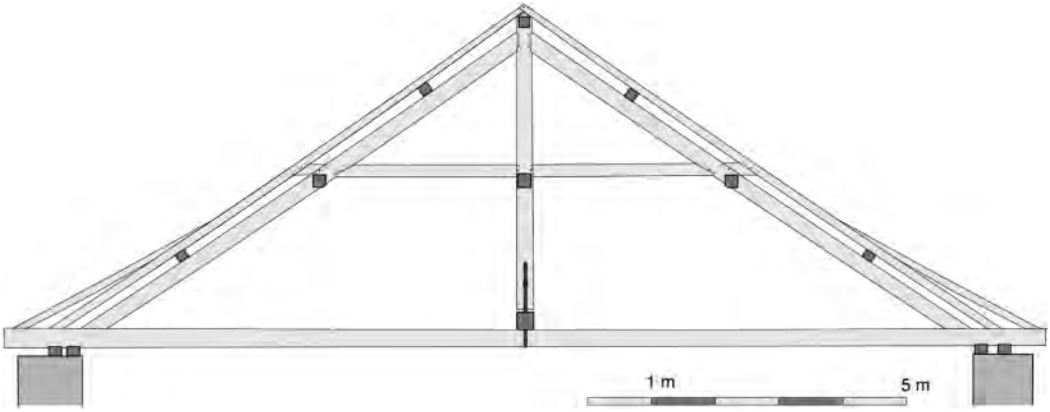

Figure 4. Total station survey of a principal truss of the reformed church at Embrach (Schäfer 2020).

Below the straining beams, a further girder runs in the longitudinal direction of the roof structure. This is tenoned in four sections, from king post to king post. The straining beams of the secondary trusses are tenoned into the girder and can therefore also be used as collar beams. Two purlins are resting on each side of the principal rafter, which are fastened with iron nails. At the ridge point the common rafters are connected with a mortice and tenon joint, and the rafter feet are tenoned into the tie-beams.

2.4 *Differences to the model*

Although the construction described has some similarities to the classic purlin roof trusses, there are considerable differences in detail compared to the Italian original. Mediterranean purlin roofs usually have no longitudinal bracing whatsoever, apart from the purlins and the roof membrane. In Embrach, however, the collar plates between the principal rafters and the girders in the central longitudinal axis are arranged to provide longitudinal wind-bracing. This additional stiffening is an improvement over the Mediterranean model and is also found in England, France and Germany (Holzer 2015: 83–84).

The horizontal straining beams between the principal rafters – instead of raking braces – are another striking change compared to the conventional solutions used in the Mediterranean area. Later, Rondelet would also notice the advantage of horizontal elements over the sloping design of the raking braces (Rondelet 1833: 132—134). In the secondary trusses, the straining beams take on the function of collar beams, as they are tenoned directly into the common rafters. This

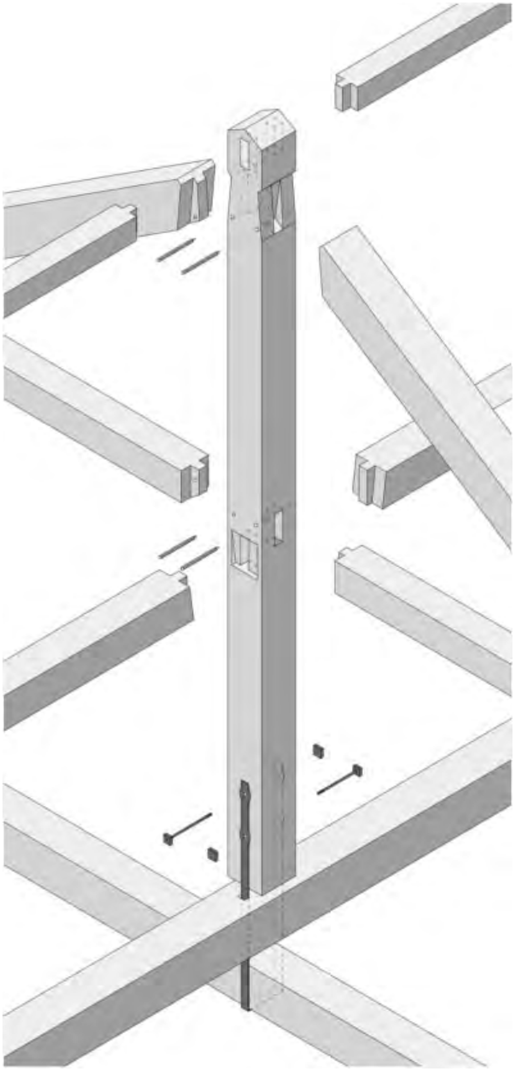

Figure 5. Explosion of the king post with the connection details (Schäfer 2020).

arrangement stiffens the secondary trusses and relieves the principal ones.

The mortise-and-tenon joint of the principal rafter in the tie-beam also strikes as a deviation from the Italian model. In Italy, there are usually abutting joints to connect the two elements, which are usually secured by iron stirrups (Valeriani 2006: 140). Almost all tenon joints are also fixed with pegs, which differs from the traditional design of the Mediterranean models.

2.5 *Context*

With the roof structure executed in Embrach, Vogel presented a construction system hitherto almost unknown to German-speaking Switzerland which he adapted to local conditions. This interpretation of the Mediterranean style is characteristic of early examples of purlin roof trusses in the German-speaking world. The use of the Italian construction principle in roofing works north of the Alps spread throughout Europe at the turn of the 19th century. Apart from the visual advantages of the flatter roof pitch, the use of this principle offered further advantages in terms of functionality, load-bearing capacity and wood savings. This development could also be traced in Germany by studies of roof structures (Holzer 2015: 93–94).

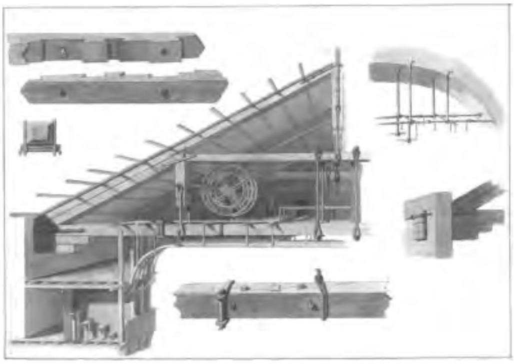

Figure 6. Construction and details of the roof truss of the Teatro Argentina in Rome by David Vogel (ZBZ, FA Escher v G 188.6, fol. 45).

In the Swiss context, the application of Embrach's Mediterranean-inspired roof system can be classified as remarkably early (secular buildings excluded). According to the current state of research, the larger churches built around 1780 in the German-speaking part of Switzerland are predominantly *liegender Stuhl* constructions with adjusted king and queen posts. A general transition to lower roof pitch took place only after 1800, but even then, baroque load-bearing systems were still used.

In this context, the building surveys by Vogel from his journey to Italy, which also show roof constructions, are worthy of interest. In a drawing of the Basilica of Saint Paul Outside the Walls in Rome, which was destroyed by fire in 1823, Vogel depicted the construction of the roof above the nave of the Basilica. There is also a drawing by Vogel of the roof structure of the Teatro Argentina in Rome, in which he illustrated in particular the details of the joints (Figure 6). The construction of the roof truss with triple king post system is shown in perspective. Two smaller detailed drawings show the scarf joint of the tie-beam, which employs a Jupiter joint and is secured by additional iron straps. A third sheet contains several roof trusses of different buildings, among them again a drawing of the roof construction of the Teatro Argentina with the corresponding dimensions of the components. Other roof trusses over a shipyard and a hall of the Toulon Arsenal are also shown, as well as the construction of the theatre of Parma.

Once again, Vogel made use of the purlin roof construction in a competition design for the reconstruction of the Rhine bridge in Eglisau ZH, destroyed in 1799.

Figure 7. Section of a wooden bridge for Eglisau. Design drawing by David Vogel (StAZH, PLAN M 10).

To shelter the bridge from the weather, Vogel designed a purlin roof (Figure 7). The basic construction of a braced king post with a horizontal compression beam and purlins resting on the principal rafters is almost exactly the same as the roof structure of the reformed church at Embrach, built more than 20 years earlier. Vogel was also familiar with the traditional construction method in this country with *liegender Stuhl* constructions.

Some designs for an oval church with pedimented fronts show formal similarities to Huguenot temple architecture. It is possible that the series is part of the competition project for the church at Embrach, for which Vogel submitted several proposals according to the protocols. Vogel planned to cover the building with a flat roof construction above the transverse direction (Figure 8).

A section of the principal truss is shown, consisting of a *liegender Stuhl* construction and an adjusted quadruple queen post system. The raking struts with pentagonal lower plates and collar plates are supported against each other by a straining beam with soulaces. The tie-beam projects far beyond the outer walls in order to also cover the porches. Short braces support the tie-beam from below. Due to its length, the tie beam consists of two parts connected with a Jupiter joint. The two outer queen posts end on girders and are presumably designed as *moises*, which include the straining and collar beam and a slightly arched brace. A second brace is used to transmit force to the outer part of the tie-beam near the wall. The structure centrally supports the ridge turret, the loads of which are supported on the collar beam by double braces.

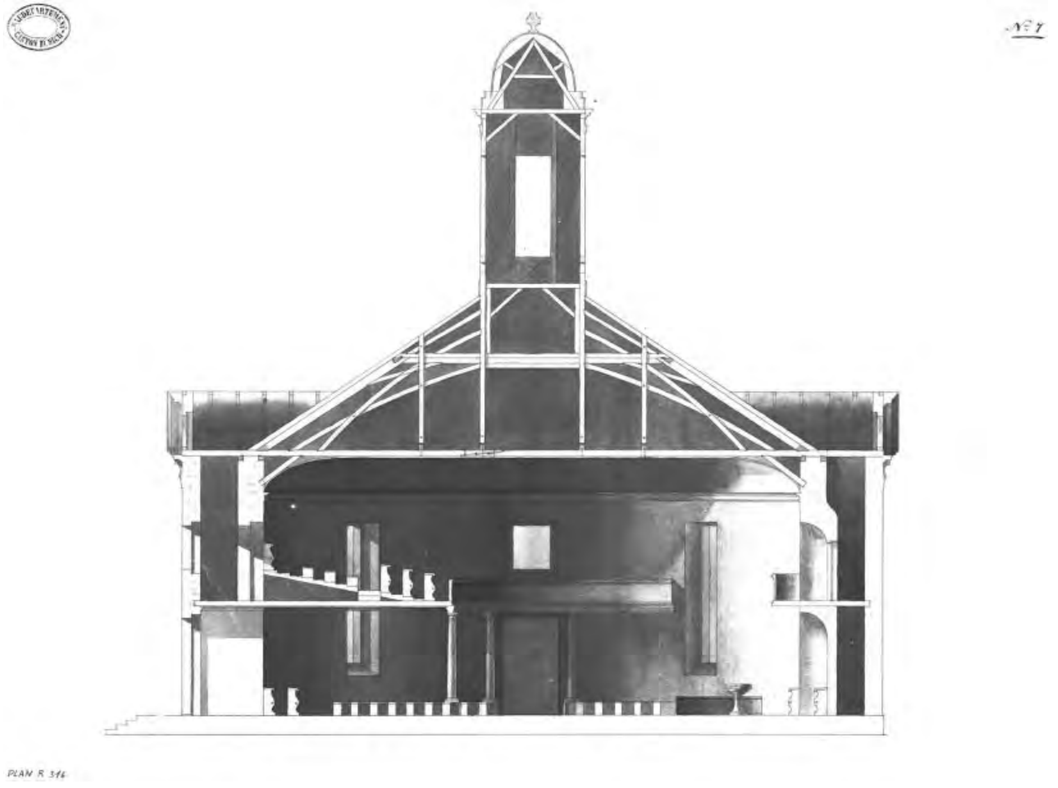

Figure 8. Cross-section through an oval church with roof construction. Design plan by David Vogel around 1805 (StAZH, PLAN R 316).

3 CONCLUSION

The richly preserved design studies and the completed church building at Embrach give an impression of how a classically trained architect thought, planned and also built in contrast to the common Swiss building practice of the late 18th century.

However, Vogel was unable to influence the local building culture with his innovative and revolutionary spirit: the purlin roof at Embrach was left without a successor in German-speaking Switzerland for many decades. Only later generations around Leonhard Zeugheer (1812–1866) were able to establish the classicist architecture and new constructive concepts. In this sense, the case of David Vogel is probably more of a curiosity that did not change the history of construction in Switzerland over the long term.

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Philibert De l'Orme roof constructions in Leiden and The Netherlands, innovation versus tradition between 1800 and 1900

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ABSTRACT: In Leiden, up to 1800, roof constructions consisting of transverse portal-shaped trusses that support purlins and rafters hardly developed. Only after changes in the building organization, during the French period (1798–1813), in which the guilds were abolished, did modernization occur, with the Philibert truss composed of short overlapping planks as a new type. Reduced wood consumption, higher living spaces, reduced risk of fire, and ease of manufacture were seen as advantages. Philibert De l'Orme's invention was rediscovered in France in the late-18th century. The introduction is likely attributable to French architects who worked in the Netherlands, or to Dutch architects under French influence. Gilly's publications from 1797 and 1798 on the Philibert construction will also have contributed. The introduction of the French Philibert truss in the Dutch roof constructions around 1800 is an example of knowledge transfer resulting from political-economic changes.

1 INTRODUCTION

Intensive research into Leiden roof constructions has made it clear that there was a gradual evolution until around 1800 (Orsel 2009; Orsel 2018; Orsel 2020). From that time on, new, modern curved plank trusses were suddenly used according to the Philibert De l'Orme principle. This article examines the gradual application of the Philibert truss in Leiden, in relation to the earliest applications in the Netherlands, and the reason for this can be linked to the abolition of the guilds. In addition, the main shape, the common construction and joinery of the Philibert trusses as applied in Leiden will be discussed. The conclusion considers why the Philibert truss eventually fell out of favour.

2 INTRODUCTION OF THE PHILIBERT TRUSS

Until the 19th century, the Dutch roof construction was a stacked construction with transverse trusses on which longitudinal beams support rafters (Janse 1989, 134–43, 249–54; Orsel 2020) (Figure 1). This typical construction form, characteristic of the Flemish-Dutch coastal area, originated from the basic common rafter roof. The roof constructions were made according to traditional construction methods, such as those passed on from generation to generation of carpenters within the guild. The guild's internal training system, with oral knowledge transfer from master to apprentice, ensured that the construction was carried out according to known, proven building construction principles and that renewal and modernization as a result of external influences were virtually excluded.

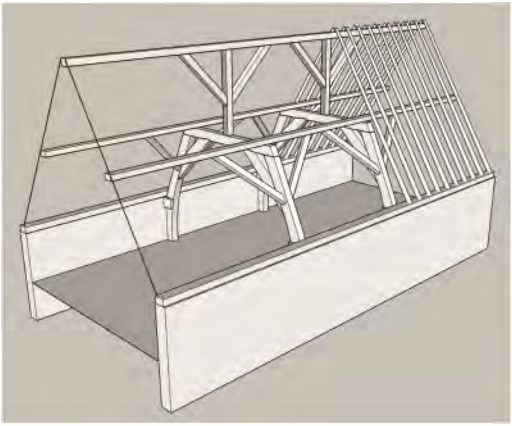

Figure 1. Traditional roof structure with stacked composite trusses. Leiden, Nieuwsteeg 17, 1592 (ELO, E.D. Orsel).

In the 19th century, a new construction, the so-called Philibert truss, was suddenly introduced in the Netherlands in addition to traditional roof structures. This is an arch truss made up of short overlapping planks. In this way, long curved truss posts could be made to replace the solid wood trusses (Figures 1–2).

The Philibert construction is an efficient construction method with economical use of materials. The truss is named after Philibert De l'Orme (1514–70), master builder in Lyon and counsel to the French king, Henry II (Janse 1989, 308). In 1561, he published his idea for a supporting structure composed of short planks (De l'Orme 1561). However, the construction had a limited application in the 16th century.

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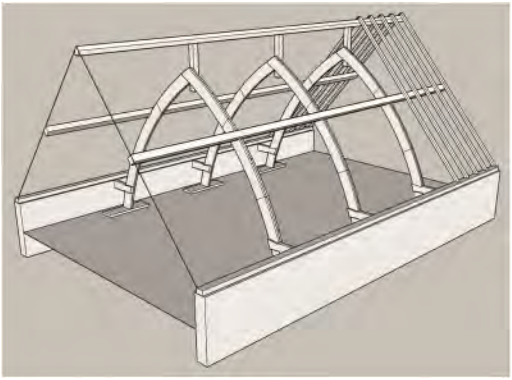

Figure 2. Modern 19th-century roof construction with Philibert trusses. Leiden, Maredijk 36, 1840 (ELO, E.D. Orsel).

It was not until the late-18th century that Philibert De l'Orme's construction was rediscovered and used again in France, after which it was also introduced in other countries (Gilly 1797; Bemelmans 1987, 8–13; Janse 1989, 308–10; Haupt 2003).

The earliest application in the Netherlands of a Philibert construction is the pavilion of Bellevue estate in Haarlem, designed by Abraham van der Hart (1747–1820) from 1801 (Orsel 2020, 217–9). The roof is formed by a series of composite curved rafters. Another early example was a wing of the Observanten Monastery in Amersfoort that was converted into an artillery school in 1804/05 (Bemelmans 1987, table 1, no. 3. Demolished during restoration). The curved composite Philibert trusses support longitudinal beams and rafters (Figure 3).

The oldest example from Leiden appears to be the design for an Academy Building from 1807 (Bemelmans 1987, 11; Heijenbrok 2007). The design by Abraham van der Hart, Johan van Westenhout (1754–1823) and Frenchman, Jean Thomas Thibault (1757–1826), architect of King Louis Napoleon (1778–1846), has barrel vaults, as was usual in French architecture at the time (Heijenbrok 2007, 291–4). The design shows arched truss structures, possibly Philibert trusses (Figure 4). This design was not realised and it remains uncertain whether Philibert trusses were intended here.

In Leiden, 44 examples of Philibert trusses are known. The oldest are, in addition to the aforementioned Academy Building from 1807, a warehouse, Langegarcht 65, from 1817–25, the Morspoort barracks from 1822–24 and a hospital, Kaarsemakerstraat 1–121, from 1827 (Figures 5–7). The latest example is Haarlemmerstraat 141 from 1888.

The Philibert construction has been applied to all kinds of buildings, including houses, warehouses, schools, barracks and coach houses (Figures 5–9). The Philibert truss was popular in Leiden in the third quarter of the 19th century with 27 examples, this is 64% of the total of 44 (how this relates to traditional trusses is unknown due to lack of documentation). The first quarter has three early examples, which amounts to 7%. Seven Philibert trusses are known in the second and fourth quarters, each representing 14%. In the Netherlands, the latest known application is Pieterstraat 44 in Goedereede from 1912 (Bemelmans 1987, table 1, no. 25).

Figure 3. Amersfoort, artillery school, 1804/05 (Rijksdienst voor het Cultureel Erfgoed, Beeldbank doc. no. 182.273).

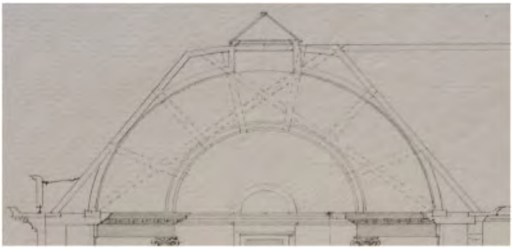

Figure 4. Leiden, Academy Building, 1807 (University Library Leiden, COLLBN, Port 14 N 154–155).

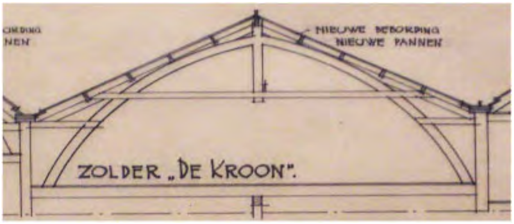

Figure 5. Leiden, Langegracht 65, 1817–25, drawing 1927 (ELO, bouwhistorisch dossier Langegracht 65).

3 TRANSFER OF KNOWLEDGE

The introduction of Philibert trusses for the Netherlands depended on several factors, but goes back to the well-known re-introduction of the Philibert construction in France. In 1783, the dome of the *Halle aux blés* in Paris saw the first reuse of I'Orme's method by the architects Jacques-Guillaume Legrand (1753–1807) and Jacques Molinos (1743–1831) and the master carpenter, André Jacob (Gilly 1797; Bemelmans 1987;

Figure 6. Leiden, Binnenvestgracht, Morspoort barracks, 1822–1824 (ELO, PV12407).

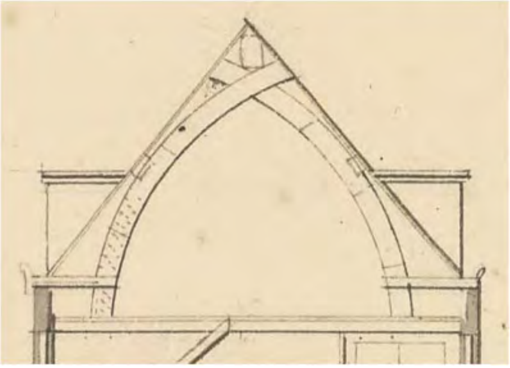

Figure 7. Leiden, Kaarsemakerstraat 7–121, hospital, 1827 (ELO, PV26301).

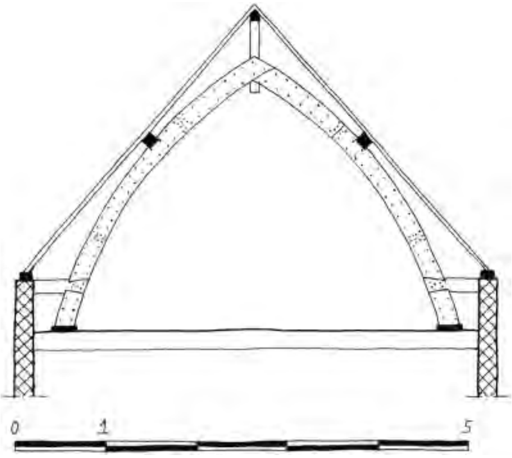

Figure 8. Leiden, Maredijk 36, 1840 (ELO, E.D. Orsel).

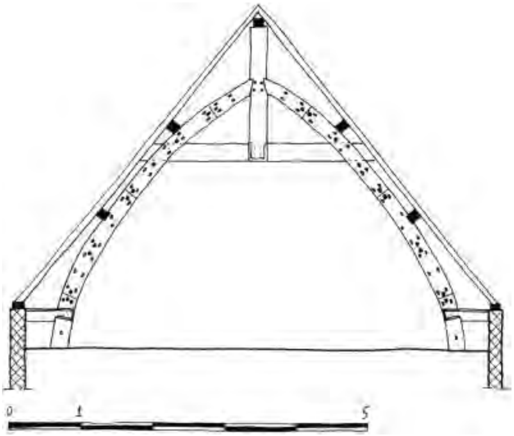

Figure 9. Leiden, Hooigracht 67, 1846 (ELO, E.D. Orsel).

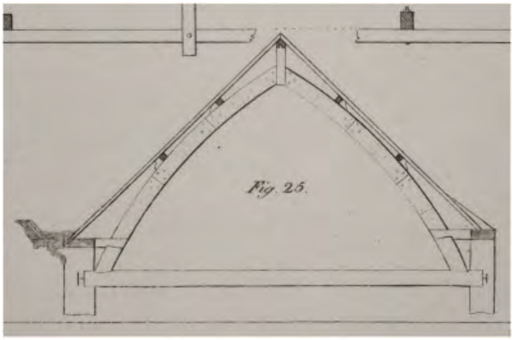

Figure 10. Example of the Philibert truss (Brade 1827, drawing 14, Figure 25).

Haupt 2003; Nègre 2015). The Netherlands was occupied by France between 1795 and 1813, during which time the guilds were abolished (Janse 1989, 295–96; Krabbe 1998, 22). The French period provided the breeding ground for the introduction of the Philibert truss by French architects working in the Netherlands or by Dutch architects who were educated by the French (Bemelmans 1987, 11). The early applications of Philibert trusses in Haarlem (1801) and (possibly) in Leiden (1807) seem to be examples of this. Van der Hart was involved in both designs, who, as mentioned, collaborated with the French architect Thibault.

With the lifting of the guild system in 1798, the internal training system was lost. This changed the building sector and created a breeding ground for a more theoretical approach and innovation. Architects, engineers and builders were now trained at drawing schools and academies, with foreign – mainly French and German, or based on them – theoretical and practical manuals and textbooks (Bemelmans 1987, 11–2; Janse 1989, 295–320; Stenvert 2013, 68–71). Due to the outdated internal guild training, self-education and self-training had already emerged in the 18th century (Krabbe 1998, 22–35).

In his German-language publications from 1797 and 1798, Gilly propagates the Philibert truss.

These publications will have stimulated the application in the Netherlands. Many of the early applications of Philibert trusses in the Netherlands are designs by construction engineers (Janse 1989, 295–96, 310). Gilly's textbook must have been available in their training. And attention will have been paid to this "modern" construction because of its advantages over traditional constructions. Willem Christiaan Brade (1791–1858), who described himself as an architect-engineer, was the author of the best-known early-19th-century manual (1827) and elaborates on the Philibert construction (Brade 1827; Krabbe 1998, 95–9). He mentions Gilly's book several times and some illustrations are also taken from it (Figure 10). According to Brade, the advantages were: reduced use of wood, more headroom, reduced risk of fire, reduced lateral pressure allowing for thinner walls, suitable application in domes and simple manufacture by means of a template. This is largely taken from Gilly's book, who in turn cites and comments on the benefits mentioned in De l'Orme's publication.

There is no sudden transition to a new truss form due to the abolition of the guild. The carpenters continued to use their familiar and proven constructions. The introduction of the new construction principle gradually followed through choices made by architects or the client, or on the basis of newly available foreign literature or Dutch construction textbooks based on it.

4 THE SHAPE OF PHILIBERT TRUSSES

The application of a Philibert construction is not determined by the shape of the roof. The Haarlem example from 1801 shows that the shape is suitable for curved roofs, as Philibert De l'Orme himself indicated. Philibert trusses occur mainly in traditional gabble and hip roofs, or modern mansard roofs. The pitch also did not really have an influence, as they occur in shallow to steep roofs. Philibert trusses are characterised by a curved truss form, built up with overlapping planks. The transverse trusses support longitudinal beams on which there are rafters or wainscoting. The new frame form is rooted in the Dutch building tradition. It is a different, local adaptation of the constructions of De l'Orme and Gilly, which are based on composite rafters, while in the Netherlands, the Philibert construction is used for the supporting trusses (Gilly 1997, 18–9). Only the oldest examples in Haarlem from 1801 and Leiden from 1807 (possibly) are comparable to the original principle. Analogous to the traditional Dutch constructive setup, the Philibert trusses have an average truss distance between two and three metres (Bemelmans 1987, 17; Orsel 2020, 176).

The curved trusses have a round arch or a pointed arch as a basic shape (Figures 2–13). Sometimes the truss posts overlap and protrude (Figures 6–7, 11). Elements can be added to this basic truss shape. These can be sole-pieces if there are parapets (Figures 4–9). In order to support the ridge purlin, it often happens that the truss is made with a ridge post (Figures 8–9, 12–13). For more stability, a horizontal beam can be used, sometimes also connecting the ridge post (Figsures 7, 9, 12). Full or partial triangular trusses of straight, solid or laminated parts can also be added to the curved truss (Figures 4, 11, 13). Curved Philibert truss posts can also be combined with straight, solid or laminated truss posts, so that the basic curved shape is partly straight (Bemelmans 1987, 17–8).

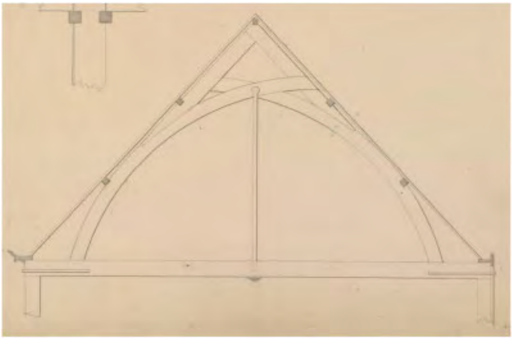

Figure 11. Leiden, Burgsteeg 14, before 1836 (ELO, PV18562.3).

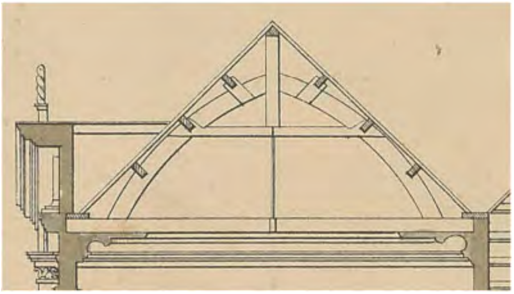

Figure 12. Leiden, Breestraat 60, 1871 (ELO, PV28987.1).

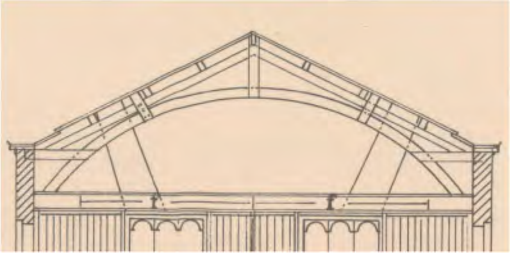

Figure 13. Leiden, Aalmarkt 9–10, 1874, drawing 1908 (ELO, PV19203).

5 CONSTRUCTION AND JOINTS

The construction consists of two or three layers of sawn pinewood planks (Janse 1989, 310–14) (Figure 7–10). Three layers are used if the span increases, roughly more than ten metres (Figure 13). The reason is that there is more strength, stability and bearing capacity. The largest span with Philibert trusses in the Netherlands was the covered riding school from 1827 of the Royal Military Academy in Breda with a width of 22

Figure 14. Leiden, Aalmarkt 4, 1862–1881 (ELO, E.D. Orsel).

metres (Janse 1989, 313. Demolished 1962). That is why these frames were built with four layers of planks. The rafter legs are made with staggered and overlapping boards of relatively limited length (0.7 to 3 metres). The curved shape is achieved by sawing the boards slightly curved, but mainly by turning them slightly in relation to each other (Figure 14).

The planks are usually joined together with iron nails, in a regular pattern (Figures 8, 14).

Square bolts have occasionally been used, sometimes in combination with wooden dowels (Figures 9, 15). The added solid parts are connected with traditional, lapped, notched and/or mortise and tenon joints.

6 DECLINE

The innovative Philibert construction gradually fell out of favour later in the 19th century, due to perceived disadvantages such as the poorer structural properties compared to traditional trusses and the higher costs due to wood loss and more labour (Bemelmans 1987, 12–3). German scientific research already showed before the middle of the 19th century that the composite structures were economically and constructively inferior to the traditional ones. (Säbel & Holzer 2012, 118). Wood saving also became less necessary due to industrialization (Haupt 2003, 1138). Iron became an important building material as an alternative to wood. Wood use also declined due to the rise of coal as a fuel and the rationalization of work processes and technological developments. In addition, transport costs decreased due to changes in transport methods. Philibert trusses were treated in Dutch construction books until the beginning of the 20th century and were still used sporadically, such as the latest example in Goedereede from 1912, already mentioned.

Figure 15. Leiden, Hooigracht 67, 1846 (ELO, E.D. Orsel).

7 CONCLUSIONS

Based on physical and archival documented Leiden and Dutch examples, it appears that a new roof construction form with Philibert trusses has been used in the Netherlands from the beginning of the 19th century. These curved plank trusses are radically different from the traditional trusses, as crafted for centuries by traditional guilds. Modernization only became possible after drastic changes in the construction world. The introduction of the Philibert truss is the result of the fact that the Netherlands was under French rule between 1795 and 1813 and that the guild system was lifted during this period in 1798. With the abolition of the guilds, there was no immediate, abrupt change or renewal of the construction form and builders continued their construction work as before. In France, just before that in 1783, the 16th-century curved plank construction by Philibert De l'Orme had been rediscovered, mainly because of its economical use of wood. This innovative construction was first used by French architects working in the Netherlands or by Dutch architects under the influence of French architects, of which the Haarlem example from 1801 is the oldest. The application of the Philibert construction will have been further stimulated by the late-18th century publications by D. Gilly who praised the various advantages, including reduced wood consumption. The form became common in the Netherlands through Brade's 1827 textbook, in which the Philibert constructions were based on Gilly's publications. Due to the combination of a changing building sector, the availability of foreign publications or publications based on them and the decisive factor of the abolition of the traditionally established guild, from the beginning of the 19th century there was room for renewal in the construction field and the introduction of the Philibert truss followed. In the Netherlands, the implementation is a local variation in which not the rafters but the transverse portal-like trusses of the traditional roof construction are carried out in the Philibert construction. The introduction around 1800 of the French Philibert truss in the Dutch roof constructions is an illustrative example of knowledge transfer and local adaptation as a result of political-economic changes.

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History of Construction Cultures – Mascarenhas-Mateus & Paula Pires (eds)

Timber roof structures of 19th-century military riding halls in Switzerland

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ABSTRACT: Riding halls were essential to military training schools during the second half of the 19th century in Switzerland. The required wide span and the fact that their roof structures were left visible resulted in fascinating timber constructions and state-of-the-art technology. Nine well-preserved halls, built in the 1860s and 1870s, were analysed, and three were chosen to exemplify the building practices of this period. The buildings were documented by on-site surveys, using a laser scanner and hand measurements. Although the halls were planned by different architects, their roof constructions are strikingly similar and were mostly executed as purlin roofs with queen-post trusses. Furthermore, the timber roofs were studied in their historical and geographical context setting them in relation to 19th-century publications. This study reveals the development of these constructions and gives an insight into their international and regional influences.

1 INTRODUCTION

This research project is part of the SNSF project "Wide span timber roofs in Switzerland". In the first half of the 19th century there was a shift in technological innovation from religious to secular buildings such as market halls, riding halls, industrial buildings and railway buildings. A particularly clear example can be seen in the remarkably well-preserved Swiss military riding halls. Up to now, very little research has been done on the construction history of Swiss military architecture. This case study will allow us to understand the state-of-the-art technology of timber construction starting in the mid-19th century and reveal the influences that impacted building practices.

In 1848, the Federal Constitution established a mandatory military service and a more centralized military system, which led to an increased building activity in the military sector. The riding hall, as a new military building typology, was essential for the cavalry during the second half of the 19th century in Switzerland. The required span of up to 21 metres and the fact that the roof structures were visible from underneath resulted in outstanding timber constructions and state-of-the-art technology.

A total of nine well-preserved halls that were built in the 1860s and 1870s were used as a case study to exemplify the building practices of this period in Switzerland (Table 1). Historical riding halls were discovered in Winterthur, Frauenfeld, Solothurn, Aarau, Thun, Basel, Zurich and Bern. The halls were documented by on-site surveys, using a laser scanner and hand measurements.

Apart from analysing the construction systems of the roofs, the detailing of the joints was also taken into account. On this basis, the buildings were compared to each other and to historical construction plans.

Table 1. Overview of the nine examined Swiss riding halls.

Location	Year	Architect	Span [m]	Truss type
Winterthur	1862	K. F. W. Bareiss	19.5	Queen-post
Winterthur	1862	K. F. W. Bareiss	14.7	King-post
Frauenfeld	1863	J. J. Brenner	17.1	Queen-post
Solothurn	1864	J. K. Wolff	19.5	Queen-post
Aarau	1864	F. C. Rothpletz	19.8	King-post
Thun	1866	F. W. Kubly	20.0	Queen-post
Basel	1869	J. J. Stehlin	18.1	Queen-post
Zurich	1869	J. K. Wolff	18.9	Queen-post
Bern	1878	A. Tièche	20.9	Polonceau

Furthermore, the timber roofs were set in relation to 19th-century publications in construction journals and carpentry treatises. Although the examined buildings were mostly planned by different architects, their roof structures show similarities. Six of the nine riding halls were built with queen-post trusses, two have king-post trusses and the youngest example has a Polonceau truss. As these roof structures mark a clear break with traditional Swiss roof constructions, this raises the question of where their influences came from.Three exemplary military riding Halls in Frauenfeld, Solothurn and Thun were chosen for further examination in this article.

2 TWIN RIDING HALL IN FRAUENFELD

2.1 *Historical context*

The garrison of Frauenfeld (Figure 1) was built in 1863 by Johann Joachim Brenner (1815–1886), a renowned

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Figure 1. Photo of the riding hall of Frauenfeld in 1866 (Frauenfeld City Archive, photo archive Bär F1.3.2.3).

Figure 2. Principal truss of the riding hall in Frauenfeld, built 1863, span 17.1 m (Tobias Lenggenhager 2019).

architect of Thurgau (Carl 2004). Brenner was presumably trained as a stonemason in Zurich. In 1833, he studied architecture at the University of Zurich. Brenner travelled for several years to Italy, France and Germany before launching his own architectural firm in Frauenfeld in 1847.

The eastern cantons of Switzerland known for mainly training artillery troops needed a bigger garrison in the 1860s when bigger weapons were introduced (Külling et al. 2015). Four municipalities applied as possible locations for the new garrison. Frauenfeld was selected based on its topography and financial means, and the construction work was carried out from 1863 until 1865.

Today, the garrison is owned by the military and the riding hall is used as a multifunctional hall. This complex will soon be taken over by the city of Frauenfeld and discussions about the further use of the buildings are still in progress.

The garrison of Frauenfeld belongs to the typology of a closed four-wing complex which goes back to the baroque building tradition in Europe (Skalecki 1992). The barracks occupy one side of the rectangular plan, while the riding hall is situated on the other side. Two wings of stables connect those parts to form a closed rectangular courtyard. Although the hall was built as part of a uniform symmetrical complex, it was given a more elaborate design than the other service buildings. The twin riding hall is the only one of its kind in Switzerland (Külling et al. 2015). In Klasen's publication *Grundriss-Vorbilder von Gebäuden von militärische Zwecke* (1890), Frauenfeld is cited as an example for military cavalry barracks.

The examination of the building archives reveals that the position and form of the riding hall was changed during the planning process. A first plan shows a single riding hall (30 × 18 m), the eaves side with the main entrance facing the courtyard.

One can find an identical disposition in the artillery barracks of Hannover built in 1857 and depicted in Klasen (1890). In a second plan, the length of the riding hall was increased to 36 m, while in a third definite plan the riding hall was doubled and rotated by 90°, turning the floor plan of the hall into a square (36 × 36 m). The main façade and entrance of the riding halls were accordingly shifted to the gable side of the building.

2.2 *Construction*

The twin riding hall consists of two identical rectangular halls with ridge roofs that are connected on the long side. Each hall has an inner length of 36 m and a clear span of 17 m. The façade on the north with the main entrances still has the original windows in the form of an eight-pointed star. Exactly the same window design can be found in the riding hall of Winterthur built one year earlier by Bareiss.

The walls of the riding halls have a timber frame construction and each support total of eight principal trusses. The main structure of the purlin roof consists of a queen-post truss that is combined with a king-post truss (Figure 2). The roof has one ridge beam, four intermediate purlins and two inferior purlins. The principal rafters are connected to the tie-beam and the king-post by abutting joints. The king-post is attached to the straining beam by a stirrup strap and is extended to the tie-beam by a vertical iron tie. The two queen-posts are held by two diagonal struts and a straining beam. The struts lie directly under the principal rafters and support them in the lower part. The queen-posts are doubled and connected to the tie-beam, the struts, the principal rafters and the straining beam with lap joints, bolts and nuts.

Two raking struts ensure rigidity of the truss and additionally support the tie-beam and the principal rafters. The raking struts are doubled and connected via lap joints, bolts and nuts.

The two intermediate purlins are held in position by purlin cleats while the other two purlins and the ridge-beam are held by the queen- and king-posts, respectively. Soulaces were installed between the queen-posts and the purlins to ensure longitudinal wind-bracing and are attached by mortice-and-tenon joints. The chamfered beams and the ornamentally profiled endings of the queen-posts show a representative ambition in the execution of the structure.

The roof structure has been well preserved with minor interventions. The bases of the trusses were reinforced by a partial doubling of the tie-beam, the struts and the principal rafters with wooden planks. The straining beam was doubled, and wall brackets were added to the wall posts to support the tie-beam and the wall plates from underneath. The main structure of this riding hall is comparably similar to the one in Winterthur, which was built one year earlier and also consists of a king- and queen-post truss where the king-post is extended to the tie-beam by an iron tie.

3 RIDING HALL IN SOLOTHURN

3.1 *Historical context*

In 1861, the city of Solothurn had the ambitions to become a military base for artillery (Blank & Hochstrasser 2008). Although the federal military department dismissed the project, the city still continued planning a riding hall as a multifunctional hall that could also be used for exhibitions and festivities. Riding hall plans of executed or planned projects from Basel, Zurich, Aarau and Winterthur served as examples for the new project. Four architects were invited to contribute a design proposal. In 1863, the project of Johann Kaspar Wolff (1818–1891) was selected and the engineer Viktor Tschuy (1823–1911) was appointed for the execution. The building, which is located next to the east gate of the former city fortifications, was erected in a very short time period of six months and opened in 1864.

The examination of the building archives confirms the influence of the aforementioned models for this project. Two of the contributions resemble the structural design of Winterthur and Frauenfeld, one corresponds to Basel, and Wolff's design that was executed is similar to the one in Zurich.

Wolff, who was from Zurich, started his apprenticeship in 1833 in Neuchatel in the office of Hans Rychner (Bauer 2014). From 1836 until 1840 he studied at the Royal Academy of Fine Arts in Munich. He then worked as a building supervisor in Zofingen and as a state building inspector in Zurich. The architectural work he completed was mainly devoted to secular public buildings. The stables that were proposed as side wings were never built because of financial issues (Blank & Hochstrasser 2008). The riding hall was used as a training site for horses until 1980 and since then has served as a venue for events and exhibitions.

3.2 *Construction*

The riding hall with masonry walls and a ridge roof has a rectangular floor plan with an inner length of 36 m and clear span of 19.5 m. The plain façade has a rustica plinth and round arched windows and doors that belong to the neo-Romanesque style developed in Munich in the first half of the 19th century (Blank & Hochstrasser 2008).

The roof is supported by eight principal trusses. The main structure of the purlin roof consists of a king- and queen-post truss (Figure 3). The trusses rest on double wall-plates and cantilevers that are attached to the wall. The roof has one ridge beam, four intermediate purlins and two inferior purlins. The principal rafters are attached to the tie-beam by a double abutting joint and end at the upper part of the king-post.

The queen-posts are supported by two struts and a straining beam. The queen- and king-posts are doubled and embrace the intersecting elements (Figure 4). The principal truss is braced by a Saint Andrew's cross in between the queen-posts and additional struts.

The king-post is not extended to the tie-beam but embraces the straining beam and the Saint Andrew's cross. Longitudinal wind bracing is ensured by Saint Andrew's crosses in between the queen- and king-posts which are attached by mortice-and-tenon joints. The two intermediate purlins are held by purlin cleats while the other purlins and the ridge-beam are held by the queen- and king-posts, respectively. The use of iron is kept to a minimum and only applied to secure the joints with nuts and bolts. In this case, the visible timber structure also has chamfered beams and the ornamentally profiled endings of the queen-posts that give the structure a more elaborate appearance. The roof structure has been well preserved in its original condition. In 2001, there was a renovation that consisted of renewing the façade plaster and the roof

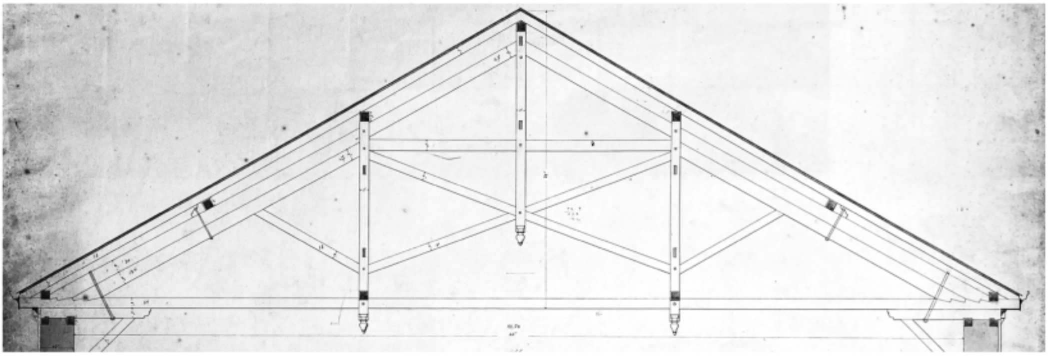

Figure 3. Historical plan of the principal roof truss in Solothurn by Wolff, built 1864, span 19.5 m (Solothurn City Archive, folder B81.91.1.6, plan XI).

Figure 4. Queen-post of riding hall in Solothurn (Russnaik 2020).

cladding (Blank & Hochstrasser 2008). As previously indicated, the riding hall of Zurich that was also built by Wolff five years later is similar to Solothurn and has the same main structure of a king- and queen-post truss that is braced with Saint Andrew's crosses. In addition, the hall in Zürich has horizontal wind bracing in the form of Saint Andrew's crosses in between the straining beams.

4 RIDING HALL IN THUN

4.1 *Historical context*

The first central military school was opened in 1819 in Thun (Külling et al. 2015). The first big military project of the young Federal Constitution was the garrison in Thun that was built from 1864 to 1867 by the architect Felix Wilhelm Kubly (1802–1872) and the engineer Leopold Stanislaus Blotnitzki (1817–1879).

Kubly, a native of St. Gallen, started studying architecture at the Royal Academy of Fine Arts in Munich in 1819 (Schubiger 2013). In 1821 he attended the École Royale des Beaux-Arts in Paris. He later travelled to Italy and Greece before opening his own architectural office in St. Gallen in 1831. His design was often inspired by French architecture of the early 19th century and the neo-Romanesque style of Munich.

Blotnitzki, who was from Warsaw, attended the Engineering Cadet School in St Petersburg and did his practical training in Odessa and Munich (Aerni 2002). After further studies in Berlin, Vienna, London and Paris he participated in the project of a railway line from Vienna to Prague. From 1845 he worked for the State Railways under Karl von Etzel in Stuttgart. In 1852 he moved to Switzerland where he was engaged in railway projects such as the Centralbahn in Basel and the main station of Geneva. One year later he became the cantonal engineer of Geneva.

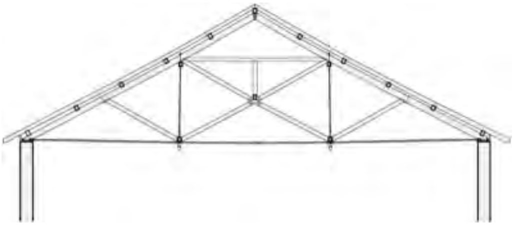

Figure 5. Principal Truss of the Riding hall in Thun, built 1866, span 20 m (K. Russnaik 2020).

In 1849, the military department was commissioned to plan the military barracks of Thun (Külling et al. 2015). Disagreements between the city of Thun and the Swiss Confederation led to a planning interruption of almost 10 years, until a competition for the garrison was launched in 1858. Although the first prize went to Caspar Joseph Jeuch, his plans did not convince the Federal Council, which then hired Kubly and Blotnitzki in 1863. The orthogonal arrangement of the garrison consists of the long main building with an exercise area on the back side. The second main element is the four-wing complex grouped around a courtyard with stables and riding halls. The two long sides accommodate the wings of stables, while the two narrow sides each consist of a riding hall. Today, the riding hall on the west serves as a gym for the military and the one on the east is used as an exhibition hall for historical military tanks.

4.2 *Construction*

Each riding hall has an inner length of 44.9 m and a clear span of 20 m. The masonry walls support 10 principal trusses. The main structure consists of a queen-post truss, with timber rafters and iron ties (Figure 5). In this case, all elements which are under tension were executed in iron while the ones under compression were completed in timber.

The queen-posts are in fact iron queen rods while the tie-beam is essentially an iron tie. The roof has one ridge beam and ten purlins that are attached to the principal rafters with lap joints. Cast-iron shoes connect the tops and the bottoms of the principal rafters. The queen rods are connected to the principal rafters and the tie-rod by a bolt and nut connection. The principal truss is braced by a Saint Andrew's cross in between the queen rods and additional diagonal struts. The Saint Andrew's cross of the truss is linked in the centre with a lap joint and reinforced by an iron plate that has an angle to hold the suspender beam. In the longitudinal direction, additional Saint Andrew's crosses function as wind bracings and are connected to the bottom and top of the queen rods by cast iron shoes. A straining beam with a short vertical post leading to the suspender beam were added later. Carpenters' joints can be found in the connection of the struts and Saint Andrew's crosses to the principal rafters with mortice

Figure 6. Cast-iron shoe at the bottom of the queen rod in the riding hall of Thun (Russnaik 2020).

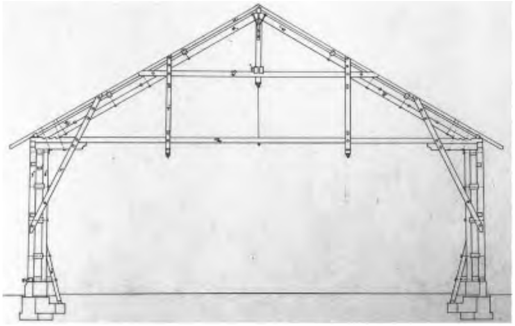

Figure 7. Historical plan of the principal roof truss in Winterthur (Winterthur City Archive, STAW plan H 246).

and tenon joints. The timber beams are chamfered ornamentally and, at the bottom of the queen-bolts, a profiled wooden cap evokes the last reminiscences of the timber queen-post (Figure 6).

The roof construction has been well preserved. Through archival research, it was possible to identify later reinforcements such as the addition of the straining beams and the vertical posts in 1958. The current condition of the structure shows a slight deformation of the principal rafters and the tie-rods. The principal rafters show a deflection of 9 cm, while the tie-rod is hanging through by 15 cm. The precise use of timber and iron according to their properties show a development towards statically determined structures and the turn towards a more engineering approach. In this aspect, the structure is comparable to the riding hall in Aarau by Rothpletz where the king-post truss also has a vertical iron bolt which is connected to a horizontal tie-rod.

5 CONTEXT

The nine examined riding halls were built in a short period of 17 years by seven different architects. Their timber structures show some intriguing similarities and yet each has unique features. This raises the question of where the influences and models came from. Hardly any specifications were made for military riding halls in the regulations for the Federal Artillery except for the ideal size that was defined to be 36 m by 18 m (Bundesverordnung 1846). The sizes of the examined halls roughly correspond to the requirements with spans of 14.7 to 20.9 m. But why the structures of the documented halls look so similar requires further examination.

Frauenfeld, Solothurn and Thun all have a low-pitch purlin roof with queen-post trusses. The initial idea behind this purlin roof with trusses that was used for the majority of riding halls originates from the traditional Italian purlin roof. These structures were being widely used in England in the 17th century (Yeomans 1992) and started to receive more recognition in France and in Germany in the beginning of the 19th century through treatises such as Krafft (1805) or Emy (1841). Both these treatises depict similar Italian purlin roofs structures such as the one used for the Teatro Argentina in Rome. In Germany, Mitterer (1817) and Romberg (1847) were also publishing these type of constructions. The fact that Mitterer published in Munich, where most of our Swiss architects studied, is particularly interesting and was surely influential for them. In this respect, it is essential to know that the number of published books on construction theory grew significantly in the 19th century. As noted in Breymann (1849), the importance of construction theory as a specific discipline of architects started to receive proper recognition and became more important in the education program. Italian purlin roofs were subsequently being projected as visible roof structures for secular buildings such as market or industrial halls, as shown in Bruyère (1823) and Brisson (1821–1825).

The choice of a purlin roof in which a queen-post truss combined with an additional king-post forms the principal load-bearing structure naturally has something to do with the span of the roof (already applied in the Teatro Argentina in 1731). For this aspect it is helpful to have a closer look at other riding halls. The famous Moscow Manege designed by the Spanish engineer Augustín de Betancourt (1758–1824) and built in 1825 is an example that was widely known through treatises such as Romberg (1847). The main structure of this hall with a span of 45cm is a purlin roof with a recursive system of queen-post trusses. The main idea was to overcome a larger span by combining as many queen-posts trusses as needed. For halls that have a span of 20 m, only one queen-post truss is needed. This is shown in Emy (1828) where two different timber structures for riding halls are compared in relation to their span. The roof truss with 20 m span which was a proposal for the military riding hall of Libourne has the same main structure of a combined king- and queen-post truss that was also applied in Winterthur, Frauenfeld, Basel, Solothurn and Zurich.

Hence the structural idea of this type of construction that was well known in Europe must have influenced our seven architects. A further look at their biography confirms our assumption. Most of the architects had studied abroad and travelled to the architecturally most influential cities in Italy, France and Germany, as was common at that time. Five of the seven architects have a biographical connection to the Royal Academy of Fine Arts in Munich. Four of them were taught there by Friedrich von Gärtner: Bareiss, Wolff, Rothpletz and Kubly. Brenner studied in Zurich and was educated by Karl Ferdinand von Ehrenberg, a former student of the Royal Academy of Fine Arts in Munich. Kubly also studied later at the École nationale supérieure des beaux-arts in Paris. The two youngest architects, Johann Jakob Stehlin (1826–1894) and Adolphe Tièche (1838–1912), studied at the École des Beaux-Arts in Paris.

To understand the development of Swiss military riding halls it is helpful to analyse the oldest example, built in Winterthur in 1861 by German architect Karl Friedrich Wilhelm Bareiss (1819–1895). Bareiss, son of a carpenter, studied at the technical building school in Stuttgart until 1841 and continued his studies at the Royal Academies of Munich and Berlin (Keller 1969). Not only did he work on different building projects, but he also worked as a teacher at the technical building school in Stuttgart before he became the building master of Winterthur in 1860.

The principal trusses of the large hall in Winterthur consist of a queen-post truss with an additional king-post truss (Figure 7). Raking struts support and stiffen the truss additionally. The queen-posts are doubled and embrace the tie-beam, the straining beam, the diagonal struts and the principal rafters, while the king-post consist of one piece which is extended from the straining beam to the tie-beam by a vertical iron tie. The six purlins are evenly distributed over the principal rafters while the ridge beam lies on top of the two principal rafters and the king-post.

A strikingly similar timber structure can be found in Breymann's *Allgemeine Bau-Constructions-Lehre, mit besonderer Beziehung auf das Hochbauwesen* which was published in Stuttgart in 1851 (Figure 8) when Bareiss worked there as a teacher.

The main structure of the hall in Winterthur can be seen as a development of the one in Figure 8, where instead of doubling the king-post to extend it to the tie-beam, the post is simply extended by an iron tie, making it more elegant to the eye. Many of the details in Breymann (1851) were adopted in Winterthur; for instance, the way the king-post is connected to the principal rafters by a y-shaped iron element, the way the doubled queen-posts embrace the intersecting elements or the way the principal rafters are attached to the struts with wooden dowels, iron nuts and bolts.

This main structure is also implemented in the riding hall of Frauenfeld (Figure 2) that was built one year later. Some minor differences can be found in the joints and the wind bracing. The struts of the queen-post truss are only connected to the principal rafter by nuts and bolts, whereas in Winterthur dowels are added. The straining beam is attached to the struts with an abutting joint and embraced by the doubled queen-post, whereas in Winterthur the straining beam is also doubled and embraces the struts. Another difference can be seen in the way the purlins are positioned and attached. Instead of being distributed freely on the principal rafter, they are positioned where the load can directly be transferred to the main structure. Two of the intermediate purlins rest directly on the queen-posts while the other two are attached to a purlin cleat and lie on the axis of the raking struts. The wind bracing in longitudinal direction is ensured by soulaces, whereas in Winterthur Saint Andrew's crosses were installed in between the queen- and the king-posts. In Frauenfeld, timber was used more sparingly and fewer carpenter joints were executed, making the construction more economical but also less stable in some areas. For example, the partial doubling of the tie-beam on the base of the truss is missing in Frauenfeld and had to be reinforced with brackets at a later stage. Some details – such as the way the purlins are placed – could be seen as an improvement of the structure by considering the direct load distribution. This detail was adopted in later riding halls such as the ones of Basel, Solothurn and Zurich.

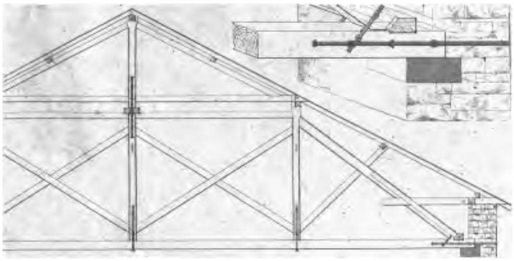

Figure 9. Construction plan for the riding hall in Darmstadt (Moller & Heger 1825: plate VIIII).

The riding hall in Solothurn built in 1864 by Wolff was also based on Winterthur and Frauenfeld. The main difference can be found in the king-post, which is not extended to the tie-beam, and in the wind bracing of the cross section. In Winterthur and Frauenfeld the truss is stiffened by the raking struts whereas in Solothurn they are replaced by a Saint Andrew's cross in between the two queen-posts and two additional struts on the opposite sides of the queen-posts. The bracing of the principal truss in between the queen-posts in form of Saint Andrew's crosses was a new development in the 19th century in Bavaria (Säbel 2017). Moller who was certainly influenced by Rondelet propagates the system of triangulation to form a more solid structure. In Figure 9, Moller & Heger (1825) presents the structure of a military riding hall in Darmstadt built in 1827 by Franz Heger (1792–1836) and shows this idea of bracing the truss with Saint Andrew's crosses. Like many of the architects of the riding halls, Wolff had studied in Bavaria where he most probably adopted this construction detail which was also used in the riding hall of Zürich and Thun. The third hall in this case study, built in Thun by Kubly and Blotnitzki in 1867, is a timber and iron construction.

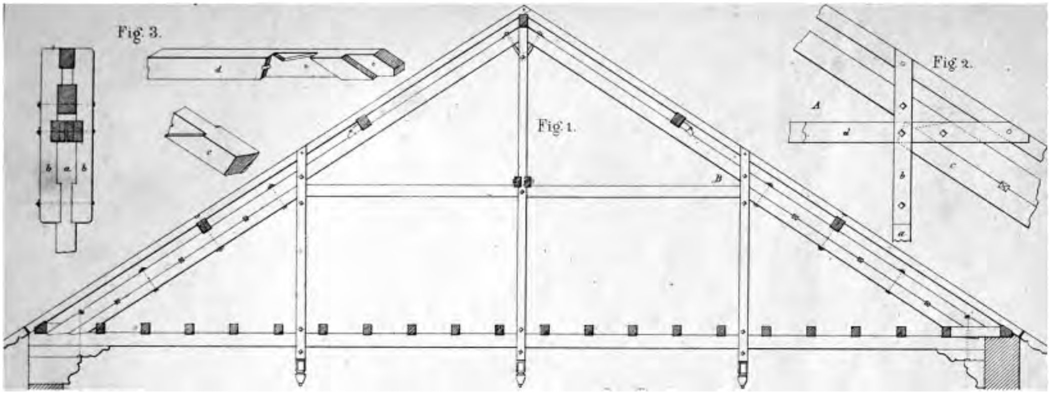

Figure 8. Construction plan for a roof truss with a span of up to 24m (Breymann 1851: plate 33, Figure 1).

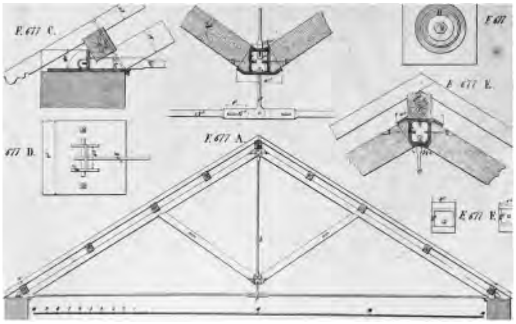

Figure 10. Roof truss with vertical iron tie, horizontal tie-rod and cast-iron shoes (Romberg 1847: plate 69).

At first sight the truss with the crossed truss bracing is almost the same as Solothurn – except for the missing king-post. The principal structure of a queen-post truss was executed with horizontal and vertical iron ties. This combination of horizontal and vertical iron ties can be seen in Figure 10 depicted in Romberg (1847). The use of iron ties in purlin roof structures was common in railway buildings such as halls and sheds, as can be seen in Eisenlohr (1852), as well as in Swiss examples such as the Elsässer Perronhalle that was built in 1860 in Basel. Blotnitzki, who had worked in railway projects in Germany, Austria and Switzerland was surely influenced by these constructions. His approach as an engineer can be seen in the precise use of certain materials according to their structural properties. Another difference in this riding hall is the use of cast-iron shoes that completely replace carpenters' joints in specific areas such as the bottom end of the vertical iron tie where the bracing is joined with the queen rod and the iron tie. In addition, iron angles, plates, nuts and bolts were applied in this construction. The only carpenters' joints that were executed were mortice-and-tenon joints in the principal truss where the struts and Saint Andrew's crosses are connected with the principal rafters. Moreover, lap joints can also be found in between the purlins and the principal rafters. Hence, the structure in Thun is inspired by the previous Swiss riding hall structures and merges them with new building technologies of railway buildings.

6 CONCLUSION

The biographies of the architects of the nine riding halls make the international influences apparent. Studying abroad and travelling to the main architectural centres in Europe became important in the education of Swiss architects in the 19th century.

In addition, increased publications in construction journals and carpentry treatises inspired these architects and engineers and led to an increased evolution of building technology. Moreover, visible roof structures gained acceptance for secular buildings through French publications as shown in Bruyère (1823) and Brisson (1821–1825). Direct influences for the riding hall structures could be traced to Stuttgart with Bareiss the architect of the first military riding hall in Winterthur and the impact of the publication on timber constructions by Breymann (1851). In Bavaria, where most of the seven architects studied, influences concerning the bracing of the principal truss with Saint Andrew's crosses were discovered and could be found in Solothurn, Basel, Zurich and Thun. Other ideas came from modern building typologies such as railway buildings, where iron was being used more frequently. Influences through the engineer Blotnitzki who worked in different railway projects were found in Thun and show a development towards statically determined structures and a turn towards a more engineering approach. Although international influences could be traced back, the architects distinctively adapted and developed their constructions according to local practices. These nine exceptionally well-preserved Swiss riding halls show a wide variety of construction details within a same building typology. They stand out as unique examples in Europe, where most of these timber constructions were destroyed during wars. Hence this case study sets a foundation and a promising prospect for further research on other 19th-century

Swiss building types demanding wide spans, such as railway buildings, factories and city halls.

ACKNOWLEDGEMENTS

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Thematic session: Historicizing material properties: Between technological and cultural history

History of Construction Cultures – Mascarenhas-Mateus & Paula Pires (eds)

Comparative analysis of bricks manufactured in the New World (1494–1544)

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ABSTRACT: This paper makes a comparative analysis of the first bricks manufactured in the New World during the first 50 years of conquest and colonization (1494–1544). Samples of bricks and tiles were taken from the sites of the ruins of La Isabella (1494), Concepcion de la Vega (1502), Fort Santiago in Fortaleza of Santo Domingo (1540), and Royal Shipyards (1544). Petrographic analysis, X-ray fluorescence (XRF), X-ray diffraction (XRD), sclerometer and Mercury Intrusion Porosimetry were performed on these samples. In conclusion, it was demonstrated that the bricks are of very good quality, made with a good low-porosity clay. The selection of the raw material and the manufacture of the brick demonstrate the deep empirical knowledge of the craftsmen who made the first bricks in the New World.

1 INTRODUCTION

Clay bricks have been manufactured and used as a building material in many regions of the world for their excellent physical and mechanical characteristics. In the Caribbean islands the use of brick arrived with the European conquerors as the native people did not use it for construction, they only used the clay to make pots.

In the New World, the first material manufactured by Europeans was the brick in 1494 in the city of Isabela. The need to build durable structures was the motivation to manufacture kiln clay bricks, because they are resistant to compression, fire, and weathering, and provide thermal and acoustic insulation.

To know the historical brick, it is necessary to carry out a series of chemical and mineralogical composition tests of clays to define the mixtures used in the manufacture of bricks because it directly influences their mechanical and physical properties.

Many studies have been carried out on the physical, chemical, and mechanical properties of the clay bricks and their use in architecture (Arce 2004; Fernandes et al. 2010; Fernandes 2019; Kagi & Ren 1995: Yavuz & Sağıroğlu 2016;). However, there are few studies on the properties of traditional clay bricks, and it is important to overcome this deficiency in the literature, especially as urban pollution, improper use of materials and lack of maintenance in most buildings (Fernandes 2019) are causing destruction of the brick. The type of clay and the techniques used by the manufacturers of these bricks are still unknown.

For this reason, the aim of this paper is to make a comparative analysis of the chemical, mineralogical, and physical properties of the kiln clay bricks manufactured on the Hispaniola island during the first 50 years of the conquest and colonization (1494–1544).

2 BRICKS IN HISPANIOLA ISLAND

In the Second Voyage, Christopher Columbus carried the order to establish cities in the New World, for which he brought a “brigade of workers, with supplies of bricks, lime and plaster” (Palm 2002). The brigade comprised masons, stonemasons, carpenters, blacksmiths, roofers, and brick builders, who, at that time in Spain, had already distinguished themselves from the potters.

La Isabela, on the island of Hispaniola now Dominican Republic and Haiti, was the first city established by the Spaniards where the first bricks and roof tiles were made. In the surroundings of the village the Spaniards found very good raw materials to manufacture lime, bricks, and roof tiles (Cruxent & Deagan 2002). Fray Bartolomé de Las Casas said that: “there was very good stone for quarrying and for making lime, and good soil for brick and roof tiles ...” (De las Casas 1987).

The archaeologist Jose Maria Cruxent, who excavated at La Isabela, found near El Castillo a 15th century pottery kiln which also must have been used for roof tiles and bricks (Cruxent & Deagan 2002).

After La Isabela, Cristobal Colon established the village Concepción de La Vega near the gold mines in 1495, and Bartolomé Colon established the city of Santo Domingo, on the eastern side of the Ozama River, in 1498. In both cities the Spaniards manufactured kiln clay bricks. From the end of the

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Figure 1. Clay on the island Hispaniola.

15th century, some problems caused the population to leave Isabela and settle in other villas, ceasing brick production in La Isabela and building new kilns in La Vega and Santo Domingo.

Commercial growth and population increase at the beginning of 16th century caused a construction boom, requiring more material than the island produced, so the Spaniards began to import, from Spain, materials including clay brick.

In 1502 Nicolás de Ovando arrived on the island, as governor of the territories discovered to that time. During his government (1502–9) he established new cities and occupied all the island's territory. At that time the crown hired builders to carry out all the works on the island, while Ovando brought construction materials such as nails, wood, and bricks.

Between 1508 and 1509, in the shipping lists of Viceroy Diego Colon's fleet, we found several records of brick shipments from Seville. For example, in 1508, Francisco de la Fuente arrived at Santo Domingo with 3000 clay bricks (Benzo 2000) and Pedro de Umbría with 10,000 clay bricks to make "the constructions of the city of Santo Domingo" (Rodriguez Demorizi 1978). In 1509 Alvaro de Briones registered 6000 clay roof tiles; Diego Díaz 1500 clay bricks (Benzo 2000); Juan de Jerez 4000 clay bricks and two dozen axes (Benzo 2000) while Tomás Sánchez registered two quarter iron, two quarter axes (weight two quintals) and 3000 clay bricks (Benzo 2000), among others.

In 1511, the crown requested that more bricks be manufactured on the island (Marte 1981). In a letter from the King to Diego Colón and the Officers of Seville, he thought it strange that there was a lack of roof tile and brick to finish the roof of the House of Hiring because there was plenty of mud and wood to make bricks on the island (Marte 1981) (Figure 1).

Immediately, Francisco de Garay installed the first kiln and produced clay bricks and roof tiles in Santo Domingo on the shore of the Ozama River, possibly from 1512. After Garay's death the factory was sold to Garcia de Aguilar in 1528, for the sum of 500 pesos of good gold (Rodriguez Demorizi 1978).

2.1 *Handmade clay bricks*

Handmade bricks are made of clay and water. First, the paste is prepared by mixing the clay and water, kneading the mixture, usually with the use of animal force until a homogeneous paste is achieved.

A few hours later, the paste is ready to be placed uniformly in a wooden kiln of the desired shape and size, usually rectangular. Before taking the clay brick out of the mold, it was left to dry for two or three days in the open air. It then went into the kiln where it cooked for about 12 or 13 hours between 900 and 950 deg. C. after which it had to wait about five days for them to cool down before they could be taken out of the kiln, ready to use.

3 CASE STUDY

To compare the bricks, five samples were taken from various parts of three cities, namely La Isabela, Concepción de La Vega and Santo Domingo. All the cities were established between 1494 and 1544.

3.1 *Isabella. First European settlement (M1 & M2)*

Cristobal Colon, on 6 January 1494, established the villa of Isabella and immediately houses for the inhabitants were built, a church, colonial admiral's house and several public buildings like the royal warehouse, powder magazine, hospital. These buildings were made of stone, clay brick, rammed earth – tapial – and wood. The clay brick and roof tile were made on site. All these buildings were built between 1494 and 1502, because after that date the city began to be abandoned.

Among the most relevant buildings are the admiral's house and the church. For this reason, brick samples were taken from both buildings: admiral's house (M1) and a sample of a roof tile from the church (M2). The dimensions of the brick could not be determined because the sample was taken from the ruins and the bricks are not complete.

3.2 *Royal Shipyards (M3)*

The Royal Shipyards, called Atarazanas, were built in the city of Santo Domingo between 1508 and 1509, the brick roofing was completed in 1544. They were used as a dockyard and warehouse to serve the purposes of naval trade for the *Casa de Contratación*.

The building is a rectangular plan made of clay bricks and stone masonry sheltered by three barrel vaults of bricks which rest on rectangular pillars and half-point arcs, both made of bricks. Each vault had three layers of clay bricks joined with lime mortar. The sample was taken from the southern vault (M3), built in 1540. The dimensions of the clay brick are 140 mm wide, 265 mm long and 45 mm thick, and weighs 2.25kg.

3.3 *Fort of Santiago in Fortress of Santo Domingo (M4)*

The Fort of Santiago, located on the grounds of the Fortress of Santo Domingo, was built in 1540 as part of the city's defensive system, and is made of clay bricks and rammed earth. Now it is abandoned.

The sample was taken from the entrance wall of the fort (M4) and the dimensions of the brick are

141mm wide, 267mm long and 45mm thick, and weighs 2.45kg.

3.4 *Concepcion de la Vega (M5)*

Concepcion de la Vega was established in 1498 and relocated about two leagues from the original site by Governor Ovando in 1504. This was the second European settlement in the New World. The city had a fortress with two towers, gold foundry, cathedral, houses, and monastery.

In 1562 an earthquake destroyed the city and now only ruins remain with part of the fort, one tower, and some walls of the church. The sample (M5) was taken from the fort, that as built between 1505 and 1515. The dimensions of the brick are 142mm wide, 295mm long and 52mm thick, and weighs 3.371kg.

4 MATERIALS AND METHODS

4.1 *Petrographic examination*

This technique allows direct observation of the mineralogy and texture of the brick and identifies the component minerals. Standard methods of minero-petrographic analysis as well as a Carl Zeiss Jenapol optical microscope were used.

4.2 *X-ray fluorescence (XRF)*

For this analysis we used a Bruker S8 Tiger with the powder sample forming a pill. The main purpose of XRF is basic chemical analysis, both qualitative and semi-quantitative, of the elements included between fluorine and uranium.

4.3 *X-ray diffraction (XRD)*

A D8 Advance Bruker Diffractometer was used to identify the semiquantitative and qualitative mineralogical composition of the samples.

4.4 *Mercury intrusion porosimetry (MIP)*

This analysis was conducted using a Porosimetry Micromeritics, model 9320, to determine the percentage of porosity of the samples, the sizes of pores between 0.006 and 360μm, the distribution, shape, and tortuosity on pores. The results were confirmed by further testing with a Quantachrome Poremaster.

5 RESULTS

5.1 *Petrographic examination*

Sample M1. There is a reddish mass and very fine and homogeneous grain. Diffused micrograms were observed, quartz grains angular and of small size, quartz in proportion of approximately 40%, some grains of altered plagioclase and potassium feldspar stained by cobalt nitrite, also altered (Figure 2).

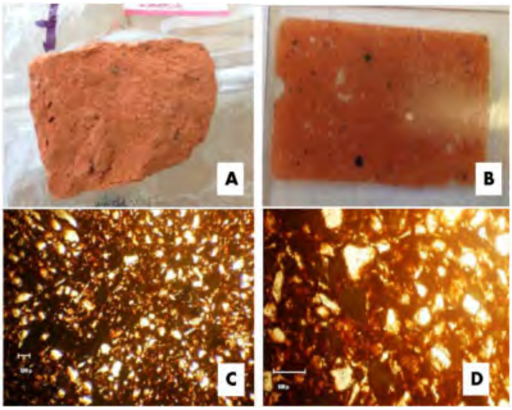

Figure 2. Sample M1: A. Initial appearance; B. Thin section; C. Microscopy X3,5; D. Microscopy X10.

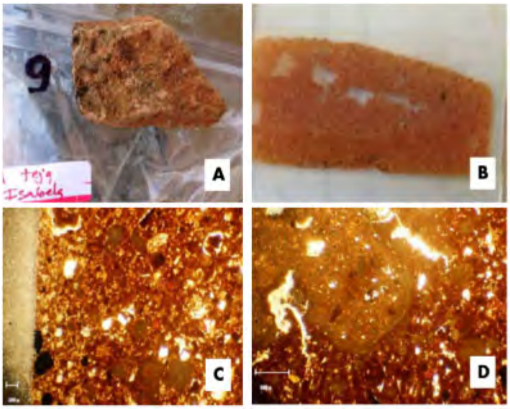

Figure 3. Sample M2: A. Initial appearance; B. Thin section; C. Microscopy X3,5; D. Microscopy X10.

Sample M2. Under the microscope, a homogeneous reddish mass and a dark isotropic mass is observed, interrupted only by sporadic grains of quartz, in a proportion of less than 2%, and some altered potassium feldspar.

With condenser the matrix appears formed by diffuse greenish and reddish grains, isotopes. Colloidal quartz and quartz are found in bigger crystalline units (Figure 3).

Sample M3. A homogeneous reddish mass is observed. Under the microscope, diffuse grains of reddish and greenish tones are observed in which grains of crystallized quartz and microcrystalline quartz both appear as degreasers. There are also small fragments of amphibole and pyroxene. Quartz grains can reach 30% of the preparation (Figure 4).

Sample M4. Under the microscope, the sample has irregular heterometric grains of angular quartz in a diffuse matrix in which reddish ochre and greenish isotropic grains and a reddish mass with whitish grains is observed. Its proportion is around 40%. Quartz

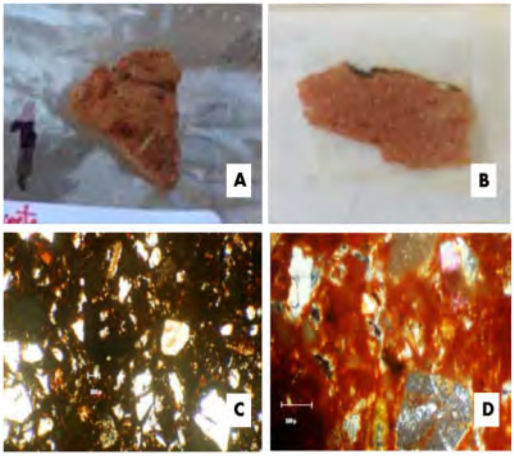

Figure 4. Sample M3: A. Initial appearance; B. Thin section; C. Microscopy X3, 5; D. Microscopy X10.

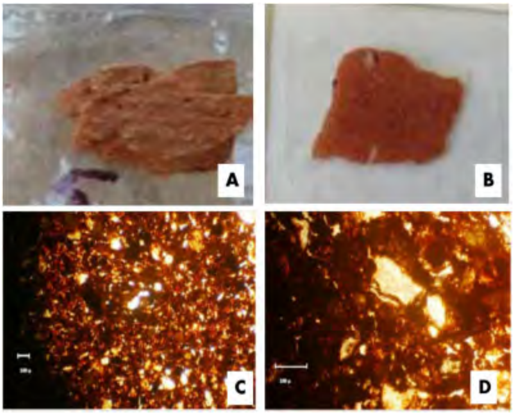

Figure 5. Sample M4: A. Initial appearance; B. Thin section; C. Microscopy X3, 5; D. Microscopy X10.

is macro and microcrystalline. It has small pyroxene grains (Figure 5).

Sample M5. A reddish colored mass with a very homogeneous aspect of fine grain and low porosity is observed. It does not present cracks or signs of alteration. There are angular fragments of approximately quartz, micritic limestone, silex, plagioclase, amphibole, pyroxene with many iron oxides (Figure 6).

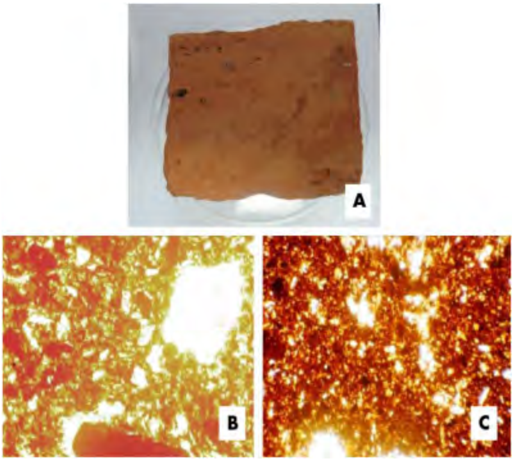

Figure 6. Sample M5: A. Initial appearance; B. Thin section; C. Microscopy X3, 5; D. Microscopy X10.

Table 1. Oxides of chemical composition.

Oxides	M1	M2	M3	M4	M5
SiO2	68.15	42.51	52.77	59.94	57.43
Al2O3	12.17	12.97	11.82	13.73	15.99
Fe2O3	6.64	12.52	13.09	12.66	10.34
MgO	1.84	2.78	2.05	–	4.79
CaO	3.70	22.00	13.39	4.64	6.41
Na2O	1.06	0.95	1.22	1.87	1.85
P2O5	1.86	1.66	1.8	1.79	0.14
SO3	0.13	0.24	0.49	1.71	0.05
Cl	0.04	0.04	0.03	0.23	0.01
K2O	3.10	2.47	1.21	1.40	0.96
TiO2	0.92	1.17	1.53	1.53	1.02
V2O5	–	0.04	0.07	0.06	–
Cr2O3	0.02	0.11	0.13	0.08	0.08
MnO	0.12	0.20	0.14	0.15	0.16
CO3O4	0.02	0.02	0.03	0.03	-
NiO	0.01	0.05	0.04	0.03	0.02
CuO	0.01	0.01	0.02	0.02	0.01
ZnO	0.01	0.02	0.03	0.03	0.02
Rb2O	0.02	0.01	0.01	–	–
SrO	0.04	0.11	0.04	0.04	0.04
ZrO2	0.08	0.05	0.03	0.03	0.01
BaO	0.04	0.08	0.07	0.04	–
PbO	0.01	–	0.01	–	–

5.2 *X-Ray Fluorescence (XRF)*

The major percentage of oxides of chemical composition of the five samples are the following: SiO2, Al2O3, Fe2O3, MgO and CaO, typical in a handmade brick (Table 1).

According to some authors, clays suitable for handmade brick should contain Silicon dioxide or Silica (SiO2) between 50–60%, aluminum oxide or alumina (Al2O3) between 21–28%, Iron (III) oxide or ferric oxide (Fe2O3) between 3–8%, magnesium oxide (MgO) between 2–5%, calcium oxide or lime (CaO) between 1–10%, and other elements (Betancourt et al. 2007; Duitama et al. 2004;.

In M2 the SiO2 is low, about 42.51% and some founded as phyllosilicates, while M3, M4, and M5 are normal, varies between 52.77 and 59.94%, and in M1 is high at about 68.15%. An excess of SiO2 can be harmful because it destroys the cohesion between the clay particles in the brick and makes it fragile and weak. The percentage in M1 is high which indicates a very sandy starting material with a lot of degreasing.

The percentage of Al2O3 varies between 11.82 and 15.99%, which is very low for a typical range of old handmade brick. This variation is possibly due to the origin of the clays, which are limestone rocks with low Al2O3 content. Having a low percentage of Al2O3 implies that the brick is not very refractory; a characteristic that is not relevant to the type of building studied.

In M1 the Fe2O3 is low for a typical range, while M2, M3, M4 and M5 have normal values. The iron oxide acts as a coloring agent and an excess implies that the paste is darker. In addition, iron oxide and feldspar lower the melting temperature. In M1, M2, M3, and M5 the MgO varies between 1.84 and 4.79%, indicating that the brick is not refractory.

In M2 the CaO is a little high, indicating that lime was added. It is common for lime to be added to the clay to lower the sintering temperature of the Silica and reduce the contractions in drying and firing, because artisan kilns do not have a uniform temperature, regularly below 800˚ C (Guerrero 2011).

Some ferromagnesian (amphibole) grains appear as hornblende in M3, and salts are poor. In M4 the presence of ferromagnesian and salts are very poor.

5.3 *X-Ray Diffraction (XRD)*

The XRD indicates the characteristic peaks of the quartz, albite, and calcite crystalline phases in different proportions (Table 2). The results are related to their sintering level, presented in Table 1.

In M1 quartz corresponds to the high proportion of silica released by XRF. The microcline is a potassium feldspar. This mineral, along with albite, contains the aluminum present in the results. Hematite and goethite contain the iron.

The clay in M2 is marly, poor in silica and rich in calcium carbonate or lime that has been added to the paste. The presence of sanidine and anortoclase (high temperature potassium feldspars) clearly indicates a volcanic origin. The diopside indicates a higher temperature than in other bricks.

Also, in M3 hornblende was detected under the microscope, suggesting a starting clay derived from the alteration of basic igneous rocks. The epidote no doubt comes from the alteration of the calcium plagioclase (epidotization) that is albitized.

The hematite in M4 indicates the high concentration of iron and the reddish color. There are no phyllosilicates, calcium silicates or other minerals that could indicate baking temperature. The gypsum comes from environmental pollution because the place is open and abandoned. Quartz and albite are observed in M5; however, the proportions are not clear from the microscopic observation. Indeed, the proportion of alumina is very low compared to silica.

Table 2. X-ray diffraction (XRD).

Composition	M1	M2	M3	M4	M5
Quartz (free silica) %	86.4	41.8	78.0	80.9	28.75
Calcite %	1.9	32.7	9.2	–	10.91
Albite %	3.7	3.9	9.1	14.9	14.91
Hematite %	2.0	–	–	3.6	–
Goethite %	1.3	–	–	–	–
Microciline %	4.7	–	–	–	–
Anortoclase %	–	13.5	–	–	–
Diopside %	–	6.6	–	–	–
Sanidino %	–	1.4	–	–	–
Hornblende %	–	–	1.7	–	–
Epidote %	–	–	1.9	–	–
Gypsum %	–	–	–	0.6	–
Silicoaluminate %	–	–	–	–	24.21
Silicate magnesian %	–	–	–	–	11.37
Iron Oxide %	–	–	–	–	9.86

Table 3. Porosity of the bricks.

	M1	M2	M3	M4	M5
Porosity %	31.83	40.26	35.75	42.85	30.19
Absolute intergranular Porosity %	14.64	7.04	16.72	23.77	31.52
Relative intergranular Porosity %	45.99	17.48	46.78	55.40	9.52
Absolute intragranular Porosity %	17.18	33.22	19.02	19.14	68.48
Relative intragranular Porosity %	53.97	82.52	53.20	44.66	9.52
Tortuosity	1.87	1.77	1.83	1.74	–
Permeability nm2	0.05	0.01	0.00	0.06	–
Radio access to pores	0.50	–	8298.64	0.58	–
Elasticity module N/m2	0.00	5.72E −10	3.24E −10	–	–
Coordination No.	26.08	14.50	27.33	36.42	–
Breaking SI press.	0.98	1.15	1.00	1.00	–
Bulk Gr/cc density	1.76	1.57	1.42	1.83	–
True Gr/cc density	2.58	2.62	2.76	2.26	–

5.4 *Mercury Intrusion Porosimetry (MIP)*

The porosity is a parameter that influences other properties. In this analysis it is expressed as a percentage. Historic clay bricks exhibit high porosity, ranging between 20% and 50% (Ramos Gavilán et al. 2018). The samples show a range between 30.19 and 42.85%, so all the samples were inside the normal ranges (Table 3).

The samples show a range from 7.04% to 31.52% for an absolute intergranular porosity. M2 being the lowest percentage at 7.04% and M5 the highest at

31.52%. Relative intergranular porosity shows a range from 9.52% to 55.40%.

Intragranular porosity can be absolute and relative. The absolute intragranular porosity presents a range from 17.18% to 68.48%; M1 being the lowest value and M5 the highest. The relative intragranular porosity shows a range from 9.52% to 82.52%; M5 being the lowest value and M2 the highest value.

The tortuosity is defined as the ratio of the average length of all particle path lines passing through a given cross-section during a unit time period to the width of the sample (Matyka et al. 2008). The samples show similar tortuosity from 1.74 to 1.87. It is low. so not very permeable. Permeability is very low. as befits ceramic material.

The access radius to the pores/pore radius is very low. indicating poorly communicated vug-type pores that correspond to trapped porosity. The resistance to decompression is low for a brick. so it would seem that it has undergone an alteration that has weakened its mechanical strength. The M3 range of decompression resistance is too low for a brick so it would appear that it has undergone alteration that has weakened its mechanical strength.

6 CONCLUSION

In conclusion. all bricks have a dark reddish color due to the high concentration of iron oxide. This coincides with the colors of the clays that exist in the surrounding areas where the bricks are supposed to have been made. Under the microscope. very diffuse greenish isotropic micrograms could be observed.

In all the samples it was detected that lime was intentionally added to the paste. possibly to lower the sintering temperature of the Silica and to reduce the shrinkage in drying and baking. because artisanal ovens do not have a uniform temperature. The aim was to reduce the porosity and permeability. as well as improve resistance to chemical attacks and to additionally increase its resistance to abrasion. This indicates that the manufacturers had a deep empirical knowledge of craftsmanship.

With XRF. it can be observed that their composition with regards most elements are very similar. which makes us think that they were all manufactured on the island of Hispaniola.

The high SiO2 content of all samples allows us to estimate a low percentage of shrinkage in bricks made from this clay due to its low plasticity. as well as a high quartz content (taken from the X-ray diffraction test) indicating a high content of defatting material (sand).

The clay brick of the Royal Shipyards – Atarazanas – (M3) and the fort of Santiago (M4) present pyroxene granites which could indicate a clay-type material from the decomposition of basic rocks. Moreover. these buildings were built in the same year. The similarities affirm that both bricks were made with the same clay. maybe in the clay brick factory that was in Santo Domingo on the banks of the Ozama River.

The clay brick of Concepción de la Vega (M5) is slightly poorer in degreasing agents and richer in carbonates and ferromagnesium. compared with the other bricks. This indicates how good the brick is. and why it has endured to this day despite neglect.

In the Hispaniola island the Europeans found very good clay and lime for making bricks and roof tiles. The brick makers knew their job very well. knew how to choose good clay and produced very good bricks. which are still in good condition despite the abandonment and lack of maintenance in which many of the colonial buildings are found.

The clay bricks we have studied affirm the historical fact that the Spaniards manufactured the first building materials in Hispaniola. From that moment on. they used local raw materials to build the great Spanish empire.

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History of Construction Cultures – Mascarenhas-Mateus & Paula Pires (eds)

The specification as an instrument for colonizing Oceti Sakowin lands

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ABSTRACT: In the 19th century, the United States of America positioned itself for industrial expansion by identifying potential territories for raw materials. Political agreements, such as treaties, formed the initial instruments for converting large swaths of indigenous lands into material territories. As treaty negotiations ended with the 1871 Indian Appropriations Act, new forms of agreements replaced them. Specifications emerged in architecture and construction as authoring tools for remote building sites as well as instruments for further delineating unresolved territories. As settlements filled presumably unoccupied lands, a growing need for lumber appeared. White pine timber offered a solution with sources identified in the northern plains, a region occupied by Oceti Sakowin peoples. A close examination of the treaties and specifications written for white pine extraction and production reveals the specification as a political instrument for colonizing Oceti Sakowin lands.

1 INTRODUCTION

Colonization extends across multiple scales in the built environment. In *At the Border of Decolonization,* Andrew Herscher and Ana María León unfold colonial processes as the “practice of seizing land from indigenous peoples. Colonization depends on the transformation of land and water into bordered territory that can be claimed, surveyed, defined, depopulated, and resettled” (Herscher & León 2020). Though Herscher and León’s writing suggests cartographic images of vast bordered territories, colonial processes impact the building and material scales as well. Beyond scale, these processes share a common foundation; they are deeply grounded in the political agreements that shape them.

During the 19th century, the colonization of indigenous lands became synonymous with treaty negotiations made between the United States of America and indigenous tribes. Treaties comprised the political agreements that displaced indigenous lands into bordered US territories. As treaty writing abruptly ended with the 1871 Indian Appropriations Act, new forms of political agreements further expanded US colonization. Though the seemingly empty territories had been surveyed, defined, and mostly depopulated by 1871, the spaces had only started to be resettled. Simultaneously, the architecture and construction community in the US had embarked on a radical restructuring of agreements through organizations that governed the social, economic, and labor culture of building sites. Specifications materialized as tools of authorship for the emerging profession of architecture (Osman 2020). As technical documents, specifications allowed architects to control building sites from a distance through the selection or disregard of certain types of work and materials. As political agreements, specifications tied architects to the vast territories needed for material extraction and production. At the building and material scales, specifications became a political tool for resettling and extracting material from colonized land.

The westward expansion of US territory was ushered through white pine lumber. Used primarily in house construction, white pine offered resilience to warping and shrinking and was easy to saw. In the 19th century, potential white pine territory was identified in Oceti Sakowin lands, leading to a series of negotiations and conflicts between white settlers and Oceti Sakowin peoples. Oceti Sakowin, or people of the seven council fires, had inhabited the northern plains region of North America for centuries. Treaties and specifications defined the political agreements for colonizing their lands. By examining initial treaties written between the US and Oceti Sakowin peoples, specifications written for white pine houses, and the specifications written by white pine institutions, this paper unfolds the specification as a political instrument for colonizing Oceti Sakowin lands.

2 TREATIES MAKE TERRITORIES

“The first pine cut in the state [of Minnesota] was in 1818, at Rum River, and was used in the construction of Fort Snelling. The fort being sufficiently advanced for occupancy by 1822, a saw mill was built under supervision of the officers at the fort, at the falls of St. Anthony near Minneapolis”. This excerpt from George W. Hotchkiss’ 1898 publication, *History of the Lumber and Forest Industry of the Northwest,* establishes an origin for the white pine lumber industry in the state of Minnesota, even before declared statehood in 1858. More importantly, Hotchkiss’ statement ignores the history of the white pine forest and its inhabitants

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prior to industrialization. For centuries, the locations delineated by Hotchkiss had been inhabited by Oceti Sakowin peoples.

Dakotas, Lakotas, and Nakotas, or Oceti Sakowin peoples, originated from a single council fire among the pine forests of Mde Wakan, known presently as Mille Lacs, Minnesota. The confederation eventually split into Dakota, Lakota, and Nakota divisions with each band occupying various locations within Oceti Sakowin lands. Solid borders and permanent dwellings did not define the land, but rather intergenerational habitation by the nomadic Oceti Sakowin peoples in the northern plains region of North America (Figure 1). Other tribes inhabited space adjacent to the lands, including Ojibwe peoples, who dubbed Oceti Sakowin peoples "*Nadeowaseau*" a word meaning "Little Enemy". The name was later shortened to "Sioux" by French settlers. By 1868, the immense expense of land occupied by Dakotas, Lakotas, and Nakotas had diminished into 25 bordered, sovereign reservations (CAIRNS 2012).

Treaties enabled the United States to acquire Oceti Sakowin lands and other indigenous lands through negotiated contracts. From 1805 to 1868, 34 treaties were negotiated between the US and Oceti Sakowin oyates or nations. The first treaty agreed upon by Lieutenant Zebulon Pike and Dakotas on 23 September 1805 ceded the land defined by Hotchkiss as the locations of the first pine cut, the first fort built, and the first saw mill established in the state of Minnesota. The first article of the treaty reads, "That the Sioux Nation grants unto the United States for the purpose of the establishment of military posts, nine miles square at the mouth of the river St. Croix …" (Treaty with the Sioux 1805). Beyond the cession of land, the treaty established two tactics for treaty writing. First, the treaty identified the Oceti Sakowin confederation as a sovereign nation, although the improper "Sioux" was written. Second, the confederation was given authority to grant land to the US. Controversy cloaked official ratification, mainly because Lieutenant Pike acted as an agent of the US without authority and because Dakota leaders, who needed translators, did not represent all Oceti Sakowin peoples. Without regard for proper representation, the treaty still established the first location of white pine extraction in former Oceti Sakowin lands and laid the groundwork for future expansion of white pine production in US territory.

The final treaty made between the US government and Oceti Sakowin peoples, the 1868 Fort Laramie Treaty, emerged after decades of conflict between the two nations. Language not only reflects an exchange of authority over the land, but also implements methods for inhabiting and constructing a more permanent built environment within the bordered reservations of the "Great Sioux Nation." Article IV of the treaty reads, "The United States, agrees at its own proper expense, to construct, at some place on the Missouri River, near the centre of said reservation where timber and water may be convenient, the following buildings to wit, a warehouse, a store-room for the use of the agent in storing goods belonging to the Indians, to cost not less than $2,500 …The United States agrees further to cause to be erected on said reservation, near the other buildings herein authorized, a good steam circular saw-mill, with a grist-mill and shingle machine attached to the same, to cost not exceeding $8,000" (Treaty of Fort Laramie 1868).

Figure 1. Oceti Sakowin Lands and potential White Pine Territory in the northern plains, 1805.

These written directives instituted the construction of Fort Bennett, a collection of timber military buildings along the banks of the Missouri River. Though the construction of Fort Bennett transpired outside of white pine territory, its position in Oceti Sakowin lands connected it to the territory's origin. Ultimately, the written directives supported the ubiquitous spread of timber construction in the US through the establishment of permanent settlements. For Lakotas and Nakotas, who were nomadic, forced settlement produced systems of enduring spatial control. As saw mills became synonymous with settlements, their construction aided colonization.

3 SPECIFICATIONS MAKE SETTLEMENTS

Hundreds of treaties were written between the United States and indigenous tribes in the early 19th century. As treaties generated territories through the inscription of bordered land, settlements arose to fill and lay claim to smaller plots (Herscher & León 2020). US Legislative Acts such as the 1862 Homestead Act encouraged and further enabled white settlers to claim up to 160 acres of surveyed plots if they could live and build upon them. In 1871, settlement making advanced colonization as treaty writing between the US and indigenous tribes abruptly ended with the Indian Appropriations Act. The Act stipulated that "no Indian nation or tribe within the territory of the United States shall be acknowledged or recognized as an independent nation, tribe, or power with whom the United States may contract by treaty …" (Indian Appropriations Act 1871). If treaty negotiations had established procedures for writing political agreements between two nations, the Indian Appropriations Act of 1871 effectively diminished the status of tribes. Dakotas, Lakotas, and Nakotas were further named wards of the US. Land was no longer agreed upon as bordered territory, but rather taken through built settlements. Years of historic conflicts such as the Wounded Knee Massacre and Battle of Little Big Horn ensued. In spite of this, new forms of political agreements evolved to aid in the settlement of former Oceti Sakowin lands.

Concurrent to the making of territories, the architecture and construction community in the US launched a radical restructuring of agreements through organizations that governed the social, economic, and labor conditions of building sites. Architectural professionalization in the US started with the founding of the American Institute of Architects in 1857 and continued with the spread of uniform instruments used for practice (Johnston 2020). Contracts, drawings, and specifications arose as agreements made among architects, contractors, and owners. As industrialization intensified access to new methods of material extraction and production, the specification materialized as the most direct link to the expansion of newly formed US territories and their raw materials. The origin of specification writing in the US underlies this territorial settlement production.

In architecture, the specification grew as a tool for authorship (Osman 2020). Though current standards issued through institutions such as the Construction Specification Institute (CSI) impact contemporary writing, specifications had developed long before standardization. Beyond the legal requirements they addressed, specifications offered a written format for translating the organization and sequence of work on a construction site from architect to contractor. The political and economic impacts of the document stemmed from the architect's agency to select or disregard certain types of work and materials for a building site. Like other architectural and construction practices in the US, specification writing can be traced to England during the mid-18th century, when architects' supervision of the site had shifted to contractors (Lloyd Thomas & Amhoff 2015). Written directives allowed architects to conduct work remotely. The written format stemmed from English patent directives used to supplement drawings. Newly industrialized tools and equipment needed writing to instruct their operation. As Michael Osman indicates in *Specifying: The Generality of Clerical Labor*, written directives carried into patent law in the US starting in the 1790s. In the lumber and timber industry, new machines powered by steam needed to be explained through writing rather than drawing; specification writing subsequently swept through industry (Osman 2020). In industrial and architectural production, specifications allowed control over the operation of equipment or the construction site in the absence of oral directives. As political agreements, specifications tied architects to the territorial production of settlements.

Once treaty writing between the US and indigenous tribes halted with the 1871 Indian Appropriations Act, the treaty expired as a political tool for colonization. Alternatively, specifications replaced the treaty as a tactic for occupying fresh territories. Specifications and treaties share some similar objectives, although primary differences lie in their explicitness and the make-up of the agreeing parties. Treaties are negotiated and made between two nations for control of territories; specifications are agreed upon between an architect and contractor for control of building sites. If treaties determined who occupied the land, specifications determined how the land should be occupied.

In the mid-19th century, some of the first specifications written in the US were by architects who designed wood-framed buildings (Osman 130). These were largely distributed through building manuals and pattern books written for houses intended to fill newly expanded US territory. One pattern book was George E. Woodward and Edward G. Thompson's *Woodward's National Architect*, published in 1869, one year after the ratification of the Fort Laramie Treaty. Based in New York, Woodward and Thompson understood the role of specification writing in maintaining control of building sites from a distance. In the introduction they write, "the forms of specifications given are such, that they may be adapted to any of the designs, so that full and final estimates can be obtained from local builders. They will also serve as hints for the preparation of specifications for any class of dwelling houses" (Woodward & Thompson, 1869).

Nineteen designs for dwelling houses and three sets of specifications categorized according to carpentry, masonry, and plumbing comprise the bulk of *Woodward's National Architect*. The authors' promise of adaptable specifications is made evident in the generic language used to define timber quality and type. "Furnish all the Timber used in the construction, of good sound square-edged quality, free from any and every imperfection tending to impair its durability or strength, and as well seasoned as any convenient market will afford. The Sills, Posts, Floor Joist and Rafters, to be of Chestnut, Pine or Spruce, and the remaining framing timber of Hemlock, Pine or Spruce, at the option of the Contractor" (Woodward & Thompson 1869). Quality was interpretable as classification systems were non-existent and the species of wood was left to local market availability. Contractors were given agency to choose the quality and type of wood depending on their location.

In spite of the generic language used for accommodating local available materials, moments of specificity do arise in modes of construction made possible through white pine. "Furnish all the lumber of white pine where not otherwise specified of good sound quality, and as well seasoned as the market affords" (Woodward & Thompson 1869). This material focused directive speaks to the ubiquity of white pine as an already available construction material in the northeast region of the US. As territories were colonized in the west, potential extraction sites such as Oceti

Sakowin lands were identified for production of the lumber.

Timber building manuals and pattern books like *Woodward's National Architect* were prolific and instrumental for occupying new US territory. The generic drawings and specifications contained in the manuals and books allowed for flexible adaptations of houses to be constructed across multiple building sites. As territories were divided and constructed upon, the collection of permanent houses along with other civic and public buildings solidified settlements into new urban towns and cities. Specifications allowed these building sites and settlements to be controlled remotely. More importantly, moments of specific material selection written in the specifications, such as white pine lumber, implicated architecture and construction in the expansion of territories needed for raw material.

4 TERRITORIES MAKE MATERIALS

Colonization of Oceti Sakowin lands was impacted by territorial settlements as well as the extraction and production of white pine lumber. As previously discussed, the first pine cut, the first fort constructed, and the first saw mill built in former Oceti Sakowin lands manifested through the first treaty negotiated between the US and Dakotas, Lakotas, and Nakotas in 1805. The treaty produced a territory identified for its raw material. Yet, raw material remains useless in architecture and construction until it has been processed and moved to a building site. Specifications make this transformation possible. In *Empire, State & Building*, Kiel Moe explains the connection between the document and territory by stating, "it is evident that every specification for construction immediately invokes a specific territory, a specific intake and circulation of matter/energy, and has a specific inherent velocity, all of which remain abstract and unknown to architects" (Moe 2017). Though specifications are briefly explored in Moe's examination of the Empire State Building, Moe's statement regarding their invisible impact upon territory is profound. White pine specifications written in the 19th and 20th centuries therefore were political instruments for the colonization of territories needed for extraction and production. Part of the invisible relationship Moe describes between architects and material territories originates from the evolution of specification writing in the US. For example, the generic language found in George E. Woodward and Edward G. Thompson's 1869 specifications pursued a particular building typology constructed with discretionary timber species. With industrialization, typologically organized specifications gave way to guides written by material producers and institutions for optimizing material selection according to lumber grades and classifications. In this way, the specification became more specific. In the US, this evolution lasted decades and unfolded concurrently with the occupation of indigenous lands. For Dakotas, Lakotas, and Nakotas, colonization occurred through the advancement of white pine. Specifications for the material evolved with it.

After the 1805 treaty negotiated between Lieutenant Pike and Dakota leaders established the initial territory for white pine extraction, other potential sites were identified and treaties followed. Despite this, turbulent encounters between white settlers and indigenous peoples surfaced frequently. Beyond the origin of white pine territory, George W. Hotchkiss' *History of Lumber and Forest Industry of the Northwest* tells of one particular encounter between a group of lumbermen and Ojibwe peoples. "In 1838, a party of lumbermen who were operating on Snake River, in anticipation of the ratification of the treaty of 1837, were attacked by a band of Ojibways and fled down the St. Croix in their canoes; a few miles below the falls they were met by the first steamboat that had ever ascended the St. Croix, and from her learned of the ratification of the treaty; this led to their return and resumption of their logging operations in which they were no longer molested" (Hotchkiss 529). This form of occupation, legitimized through treaty making, connected territorial control with material production.

Extraction makes evident the latent potential of white pine until production renders it useful for construction. Saw mills and forts were essential to this production. Saint Anthony Falls, the only major natural waterfall on the upper Mississippi River, became the site and power source for the first saw mill in former Oceti Sakowin lands. Built in 1822, the saw mill resulted from the 1805 treaty and the subsequent construction of Fort Snelling. Forts not only reinforced points for trade, but also the protection of material production. In 1858, settlements such as Minneapolis and Stillwater arose from the territory to help sanction statehood for Minnesota. By 1870, both settlements had grown into cities with 17 saw mills between them. Together these mills produced over 200 million feet of lumber, 100 million shingles, and almost 50 million laths in 1873, all valued at seven million dollars (Hotchkiss 1898). Though processing white pine developed as a lucrative economic venture, moving the material was limited. Lumber had to be rafted to points along the Mississippi and St Croix Rivers. The introduction of railroads into the US landscape brought forth methods for moving white pine outside of the territory.

In the second half of the 19th century, white pine extraction and processing had already pushed Dakotas to western lands occupied by their Lakota and Nakota kin. The open lands guaranteed a nomadic life for following and hunting bison. However, the open land also provided potential ground for US railroad expansion. Beyond ending conflict and establishing a more permanent built environment, the 1868 Fort Laramie Treaty also introduced railroad construction to the remaining Oceti Sakowin lands. Article XI compelled Lakotas to relinquish territory outside of defined reservations and to ignore US settlers traveling through the territory. Railroad construction dominated

Figure 2. White Pine Territory and Oceti Sakowin Reservations in the northern plains, 1890.

the explicit intentions of the agreement. Article XI reads, “And they, the said Indians, further expressly agree: First, That they will withdraw all opposition to the construction of the railroads now being built on the plains. Second, That they will permit the peaceful construction of any railroad not passing over their reservation as herein defined” (Treaty of Fort Laramie 1868). Railroad construction was tied to the territorial implications of white pine extraction and the further colonization of Oceti Sakowin lands. As railroads populated new US territory, new methods for moving materials from Minnesota’s saw mills prevailed. By 1880, Minnesota dominated white pine production in the US; “lumbering” in Minnesota became synonymous with white pine (Figure 2). More first class saw mills and lumber companies appeared throughout the state. Directories such as Rand McNally & Company’s 1891 and 1893 *Lumberman’s Directory and Reference Book of the United States and Canada* categorized wholesale, retail, commission dealers, and manufacturers according to location and the types of timber sawed or dealt in. The reference book also offered rules for inspection, classification, and measurement of lumber and provided state laws for lumbering. Finally, the book indexed hundreds of railways, water routes, and express companies for moving material. Directories like these put forth initial standards for developing the lumber industry and solidified extraction and production practices essential to colonial tactics in the US.

At this point, lumber manufacturers and institutions transformed specification writing practices by issuing optimized guides for architects to reference. Bureaus and Associations formed to market lumber for use in construction. In 1915, the White Pine Bureau organized and established its headquarters in St Paul, Minnesota across the river from the white pine saw mills. The Bureau represented two White Pine organizations: The Northern Pine Manufacturers Association of Minnesota, Wisconsin, and Michigan and the Associated White Pine Manufacturers of Idaho. Responsibilities of the Bureau included promotion through publications such as *The White Pine Series of Architectural Monographs* (Whitehead 1917-8). As these books exhibited structural and architectural applications, the bureau offered a more direct guide for specifying the material in the 1917 *White Pine in House Construction and White Pine Standard Grading Rules.* Organized according to standards in three territories, the stated purpose of the guide was “to furnish Architects with such authoritative information as will enable them to easily and correctly determine and as a result to properly specify the various grades of White Pine Lumber desired for use in house construction” (Lindsay 1917).

Because natural inconsistencies such as knots and warping were common in lumber, the aim of the manual was to “harmonize the natural differences which exist in the characteristics of the different stocks” (Lindsay 1917) in order to create equal market values. To use the guide as a writing tool, architects first determined the territory from which the white pine would be extracted, such as the Northern Pine Manufacturers Association’s territory in Minnesota, Wisconsin, and Michigan. Then, a class of use was selected. Class one referred to houses of the highest grade in which quality outweighed costs. A class three house elicited cheapness in which cost was prioritized over quality. Class of use determined the subsequent grading rules for white pine. Next, architectural elements and their location within the house were considered. Sill & Posts, Box Sills, Joists, Floor Linings, Studding, Rafters, Sheathing, Cornices, Facia, Shingles, and Lath were a few of the 31 architectural elements categorized. Finally, a grade of white pine was selected according to its location in the construction of the house. White Pine Finishing, Beveled Siding, Flooring, Shiplap, Grooved Roofing, Common Boards, Fencing, Dimension and Timbers, Thick Common Lumber, Factory Lumber, and Lath could be selected according to a letter grade (B through E) or a number grade (one through five). Photographic reproductions and descriptions of the grade, stock sizes, recommended uses, and approximate differences in cost between grades accommodated this information in order to solidify the architect’s decision. The method of selection considered in the guide optimized white pine specification writing for architects. The *White Pine in House Construction and White Pine Standard Grading Rules* directly connected resulting specifications to a territory. Unlike *Woodward’s National Architect,* which simply suggested white pine, architects in 1917 could determine which territory white pine would be sourced from. In the publication, grades and lumber sizes were explicit; implicit were processing and movement locations as well as trees and land needed for extraction.

5 CONCLUSIONS

From the first white pine tree cut along the Rum River in 1818 to the material’s standardized production, specifications written for white pine construction were entangled in the territorial marginalization of indigenous lands. Specifications included in building manuals, pattern books, and manufacturers' guides implicated architecture and construction in the historical transformation of Oceti Sakowin lands into white pine territory. As political agreements, treaties and specifications are both accountable for the creation of territories, although the delineation of seemingly unsettled land is more directly linked to treaty negotiations. Yet, specifications create an initial need for territories and the raw materials they possess. The increased selection of certain materials and products expand territories to meet demand. The evolution of white pine specifications from the mid-19th century to early 20th century further supports this correlation. Generic language written in pattern books such as *Woodward's National Architect* of 1869 indicate unknown territories for the extraction and production of lumber. In the book, directives written for houses intended to resettle newly acquired territories in the US offered substitutes in the absence of materials like white pine. Later specifications written in the early 20th century by institutions such as the White Pine Bureau indicate a shift in precision. As territorial borders and locations solidified, so too did points of extraction, saw mill construction for processing, and railroad expansion to move the material. Specific territories advanced precise specifications. Size and quality of the material were meticulously considered. In architecture and construction, the effects of white pine extraction and production in former Oceti Sakowin lands extend beyond a simple reckoning with historic colonial practices. Instead, specifications must be understood as instruments for connecting seemingly benign material selection to vast territories.

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History of Construction Cultures – Mascarenhas-Mateus & Paula Pires (eds)

Earthly beings and the Arts and Crafts discourse in the Cape: Conflicted and contradictory (non)appropriations of vernacular traditions

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ABSTRACT: The arrival of Arts and Crafts-oriented architects in Cape Town from England and Scotland towards the end of the 19th century brought specific attitudes to building materials to the Cape. Whilst they abhorred corrugated iron, these architects were also primed to value vernacular architecture – on its own terms but also as a resource for modern interpretation. This paper subjects the emergent contradictory discourse and its ambivalences about settler and native mud and thatch vernacular architectures to scrutiny. The general prejudice against 'native' mud architecture was born out of 'Englishness' white supremacy such that the contradictions and ambivalences in the attitudes towards these two vernaculars were papered over through racist discourse. On top of this, it finds that the contradictions were resolved by separation of 'native' and settler vernacular through simplified spatial configurations – round and square – rather than trying to parse what was a strong homology in building materials.

1 INTRODUCTION

"Now the subject of Material is clearly the foundation of architecture, and perhaps one would not go very far wrong if one defined architecture as the art of building suitably with suitable material".

William Morris, *The Influence of Building Materials Upon Architecture*

"It is a maxim among the races that build soundly that wherever possible indigenous materials should be employed as tending to yield more harmonious and lasting results that can be obtained by importation."

William Delbridge, *Our Own Materials*

Mud is banned. It is an inappropriate material. So says a South African government gazette (2013) pertaining to the building of schools. This is surprising given the opportunities mud offers for low-cost, high-impact sustainable architecture, but also, given the local and global shift in discourse towards valorising and valuing "African" architecture and identity, for example, a shift in editorial policy at The Architectural Review (AR Editors 2020). In the post-apartheid context, mud, one might think, might be promoted rather than banned in a country where strong vernacular traditions in mud-building once existed – although there is evidence that this anti-dirt attitude is shifting, particularly in the Free State Province (Malatji 2020).

But it is also not surprising. Mud, and "native" vernacular architecture more generally, has long had a troubled, ambivalent and contradictory relationship with capital 'A' architecture and officialdom in South Africa (Coetzer 2016). The originating contradictory fault-lines are most vividly exposed in the Arts and Crafts discourse as it engaged in the early 1900s two kinds of vernacular architectures at the Cape, namely, a settler architecture called 'Cape Dutch' (Figure 1) that was universally valorised, and also what was called 'native' architecture (Figure 2) which was mostly denigrated – despite both architectures being built out of the same building materials of mud and thatch. With reference to architectural journals and conference papers from the first half of the 20th century, this paper will point to this complex and self-contradicting discourse which was temporarily resolved by a shift away from building materials as a signifier of otherness to spatial arrangements as the identifying problematic condition of 'native' architecture. This was through a two-fold move that not only continued to identify the predominantly circular structures as problematic, but also their single-space interiors as being a lesser version of the 'correct' subdivision of space into rooms for specific kinds of inhabitation suitable for English middle-class living. This paper also suggests that the evident rise in interest in African vernacular architecture, ironically around the beginning of the official implementation of apartheid in 1948, possibly helped reinscribe an Arts and Crafts ethos of design-through-context back into the emergence of South African modernism as part of 'the other tradition' of modern architecture.

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2 VALORISING SOME EARLY BEINGS – DENIGRATING OTHERS

The foundational importance of the Arts and Crafts in the development of modernism was pointed to by Pevsner (1936) – not only in the development of 'honest' practical good design but through the performative and inventive act of design-through-context as a rational or 'honest' way out of stolid debates about style. In the Arts and Crafts architectural world, context – geographical, cultural, material – should be everything. This explains the importance of vernacular architecture as locale-specific, ready-made examples of buildings well-fitted to their context – and not just something to fit in with out of polite deference. As hundreds of years of embodied research and development, the vernacular examples provided Arts and Crafts architects with the knowledge of what worked where and where effective – and cost-effective – local materials could be found.

Indeed, in a paper, *The Influence of Building Materials Upon Architecture*, William Morris (1902a: 246, 248, 264) defines architecture as the "the art of building suitably with suitable materials". He continues that architecture should "begin with considering what material lies about us, and how we are to use it, and the way to build it up in such a form as will really put us in the position of being architects", which in turn brings forth a "building which really forms part of the living shell and skin of the earth on which we live". The romantic organicism of Arts and Crafts architecture – that buildings should be 'living' earthly beings – is reiterated in a concluding reference to vernacular architecture and what he notes as its beautiful buildings:

> "No doubt the great reason why that was so was because the people who built them were traditionally acquainted with the best means of using the materials which happily for them, they were forced to use; the materials that were all round about them in the fields and woods amidst which they passed their lives" (Morris 1902a: 264).

Finally, is not surprising that a follow-up paper, *On the External Coverings of Roofs*, Morris (1902b: 269) ends with a table of good and bad roof coverings where "Corrugated Galvanized Iron and Zinc" is noted as "now spreading like a pestilence over the country"; over and above its disparaged aesthetic appearance, as the premiere building material of globalization, it is the antithesis of a locally-sourced and locally-made vernacular architecture. From Morris, then, and Arts and Crafts ideologues, we can expect a homology between the building materials and earth-bound locality of a vernacular architecture that gives the building material a kind of an animating life-force that is said to be present in nature itself.

Indeed, the arrival of a professional class of architects at the Cape from England and Scotland in the late 1800s onwards can be said to have coincided with the emergence of the Arts and Crafts as a fairly dominant ethico-ideological – the ambition in Arts and Crafts discourse from Marx to Morris is not just to describe the world but to change it, for the better – comes an onward discourse and ethos in the practice of architecture at the time. The shadow of Ruskin and Morris loomed large over architectural thinking in the British Empire – even if their precepts were not strictly adhered to. Moreover, the ethos of Arts and Crafts was carried through in the beginning life of journals such as *The Architectural Review* which started out with the telling subtitle, 'For the Artist and Craftsman.' Arts and Crafts architects and work dominates *The Studio* and the short-lived *Architecture: a monthly magazine of architectural art*. These journals were a lifeline for displaced and settler-born colonial architects who needed to connect to 'home;' as identities were displaced, they needed to be bolstered by more explicit and overt identifiers.

In South Africa, or rather the Cape Colony and later Cape province, the predominance of Arts and Crafts ethos was solidified through William John Delbridge, an architect and later president of Cape Institute for Architects who also started the Institute's unofficial journal, *Architect, Builder and Engineer* (Fisher 2015: 74) It is through Delbridge's writing and editorship – as well as government reports on 'native' housing – that the ambiguous and contradictory discourse on the desirability of settler Cape Dutch versus 'native' building materials and architecture was set.

The Cape contained many examples of what became known as Cape Dutch architecture (Figure 1) – a Dutch-originated settler architecture that used local resources and building materials in an inventive reworking of the western classical tradition – pointedly, built by slaves from the spice-route trade-ports. It is characterised as having iconic whitewashed gables set against thatch roofs and dramatic mountainscapes. As I have noted elsewhere (Coetzer 2007), this settler architecture provided a convenient, ready-made, European-inhabited territory, legitimising British claims to the land whilst unifying English- and Afrikaans-speaking, white South Africans alike in the Empire's expansionist ambitions. The South African Prime Minister, Jan Smuts, noted as much in the foreword to Dorothea Fairbridge's (1922) expository *The Historic Houses of South Africa*. Furthermore, Cape Dutch revival architecture, brought about largely due to the efforts of Herbert Baker and his partners Francis Masey and Frank Kendall in the early 1900s, also somewhat successfully established Cape Dutch briefly as a national style.

It is important to note that, apart from being a useful tool in the establishment of white supremacy – for example, leading up to the Union of South Africa in 1910 as a union of white people through a series written by Francis Masey called 'The Beginnings of our Nation' – Cape Dutch architecture also embodied the ethos of the Arts and Crafts movement and its concern with locally-sourced and appropriate building materials. Its set room widths, and hence its growth as

Figure 1. Meerlust Dovecot. Photograph by Chris Snelling.

distinctive T, H and U-shaped plan-forms, were determined largely by roof spans limited by Afromontane indigenous forests, whilst the reed thatch was ubiquitous in the landscape. One of the distinctive material conditions of the Cape Dutch homestead was its use of sundried bricks or stone rubble walls hand-plastered with mud and then lime-washed. This visually striking surface was sculpturally plastic when seen at a distance but also alive with a range of hues when its irregular shadowed surface was viewed up close. As Delbridge (1934: 3) notes:

> "Bright surfaces to receive the grateful and graceful shadowing of trees, subdued light secured through heavy but appropriate shuttering, thick walls and thatched roofs to keep out the heat – all these and similar things are written on the pages of our local architectural history book for our instruction".

Similarly, the local 'native' vernacular – in its many and varied forms and material use – also presented a rich lexicon for possible appropriation and reinvention along Arts and Crafts precepts (Figure 2). It should be noted that, unlike other Dutch-originating settlements like Batavia/Jakarta, the Cape did not have a pre-existing urban built environment that settlers encountered but rather a transhumant and mobile architecture of reed mat huts. Nevertheless, there is little evidence of any curiosity of 'native' architecture as an extant vernacular – certainly not in the pages of the *Architect, Builder & Engineer*. It was only in the 1940s and 1950s, in *The South African Architectural Record*, that various authors and researchers such as Betty Spence, Gilbert Herbert, Barry Biermann, James Walton, and even Nikolaus Pevsner himself, made a sincere effort to engage 'native' vernacular architecture as a possible source for contemporary architectural design. Indeed, Betty Spence (1940: 387) noted:

"South Africans are too inclined to look overseas for inspiration…Cape Dutch architecture has been admired by other countries thus its position is accepted, and, by most, forgotten. The indigenous architecture, that of the Native, has never been considered at all".

When Delbridge did engage African vernacular architecture, it was in reference to a possible solution to the emerging housing crisis brought by increasing migration of black South Africans to city centres. This writing paralleled a global concern for, and rise in discourse on, state-provisioned housing at the end of World War One and a focus on working-class living conditions in the context of the 1918 influenza pandemic. For example, after identifying four native houses 'types' in an editorial called 'Housing,' Delbridge excluded thatch or reed structures and recommended "... a solid type of construction would appear to be preferable, providing this is within the scope of the ability of which the local native workers are capable" (1923: 17). There is scant evidence of architects or officials at the time valuing anything in African vernacular architecture other than from its economic potential in reducing the cost for the state and municipalities in the provision of housing. The closest Delbridge came to any kind of appreciation of native architecture hardly carries the same sentimentality that William Morris gestures too at the start of this paper as a "building which really forms part of the living shell and skin of the earth on which we live":

> "The [native] procured his mud and reeds for thatching his hut direct from Nature and with the assistance of his womenfolk built a shelter according to his needs; not injurious to his health and in the same simple and instinctive manner as that in which a bird builds its nest" (1927: 1).

In fact, the opposite is true. In the ongoing concern for housing, Delbridge compared the 'native hut' to a 'complicated villa':

> "No sewing rooms, boudoirs, studies, offices, billiard rooms and music salons, or other apartmental concomitants of a complex social life enter into the picture, and the problem being thus reduced to the simplest possible elements is one which should be capable of a simple and satisfactory solution…. Simple, however, as the needs may be, there are certain requirements that must be satisfied in every reasonably human habitation, and those requirements are stated as follows: – The need for shelter, warmth, reasonable privacy, the storage of food, attention to hygiene, durability, comfort, and ease of ingress and egress. Most of these requirements are ignored in the ordinary [native] hut, but all of them are met singly in varieties which we have had opportunities for seeing and studying upon records. the ordinary hut contains little, if any, means of egress for the smoke of a fire from within, takes no thought for the necessity of food storage, gives a maximum amount of inconvenience in ingress and egress by reason of the smallness of its entrance doorway and the awkwardness of the placing of its roof-props from within, takes no account of sanitation owing to defects in light and air, has no arrangement for privacy, and

Figure 2. Taung hut with a mosaic pattern, n.d. Photograph by James Walton, courtesy of the University of Stellenbosch.

> few, if any, of the requirements incidental to the lowest conceivable standard of human comfort" (1923: 10).

Delbridge's scathing dismissal of a vernacular tradition – one which his sense of white supremacy or cultural jingoism made him unable to appreciate the nuances of or even bother to understand – can be seen simply as part of a long line of attacks that began in earnest with the first missionaries in southern Africa aiming to 'rectify' the circular plan-form into more 'correct' English ways, as Jean and John Comaroff (1997: 287) have shown. Indeed, as the state moved to compel urban areas to provide segregated rental housing for black migrants to cities the demand for housing options was addressed and debated through various state initiatives such as the Municipal Control of Locations conference in 1920. Here F A Saunders (fellow of the Royal Institute of Public Health, Fellow of the Society of Tropical Medicine and Hygiene) promoted mud-plastered sun-dried bricks with "iron or thatched roof, mud floor or wooden floor" to be built and reserved specifically for "Christians", meaning Africans who were assimilating to Western modes through rectangular dwellings (1920: 9–10). On the other hand, "wattle and daub round huts would be appreciated by all except the Christians, but they would not be so durable as the square houses". As one example of how administrators and experts typically viewed the future city dwellers and the value of African vernacular architecture, Saunders went on to note 'it is as natural for a native to live in a round hut as a snake to live in a hole.'

Indeed, the authoritative power of *The Spectator* even legitimized the construction of permanent rammed earth buildings in Camps Bay, which, despite the City of Cape Town (1920) acknowledging was against their own building regulations, was nevertheless still approved. Apart from the legitimizing power of instructions from 'home' the enthusiasm for rammed earth can be understood through its requirement for shuttering and the orthogonal plan-form that it tends to generate; houses of mud could be built straight and compartmentalized correctly.

In the end, the pre-apartheid state drove housing delivery in the 1920s to 1940s through prescribed model cottage house-types rather than have mud enter the cities – all of this while the tally of Cape Dutch earthly national monuments rose sharply – including unstately buildings such as the dovecot at Meerlust (Figure 1). Englishness, and the romantic concern for the cottage as an anti-urban bolstering of the correct way to live, gave South Africa a relentless suburbia that translated into the disempowering spatial dislocation of 'the township' (Coetzer 2013). The story that begins with Cape Dutch homesteads as exemplars of an Arts and Crafts sensibility ends with the scientifically appraised and ubiquitous apartheid-era housing-unit called the 51/9 NE; the ninth iteration in 1951 of housing for non-Europeans (Japha 1998: 422–37). Needless to say, it was bereft of either Arts and Crafts or 'native' vernacular niceties. Ironically, however, one of the research architects involved in its development, was also a scholar and champion of both Cape Dutch architecture and African vernacular architecture. Barry Biermann's writing and work helped establish modernism in South Africa as part of "the other tradition" (St. John Wilson 1995) that was more responsive to the climate, culture and building materials of the region (Saunders 1920). If the Arts and Crafts movement could not hold Cape Dutch vernacular and native vernacular in the same valorised space, it took one of the architects of apartheid's most successful housing strategies to realise their homology.

The appearance of Barrie Biermann here brings us to another elliptical or flywheel movement of ideas that this paper points to: Nikolaus Pevsner, as the editor of *The Architectural Review* and a selective champion of Arts and Crafts beyond the stylistic regression it inevitably fell into, helped legitimise the study of African vernacular architecture in South Africa (Dainese 2015: 443–63). Similarly, modernist enthusiasts like Rex Martienssen as editor of the *South African Architectural Record* in the 1940s helped promote articles by Betty Spence, Gilbert Herbert and Barry Bierman that validated African vernacular architecture. Although they can be seen as problematic reinscription of Western or colonial gaze on 'other' subjects – as Betty Spence herself notes – their writing was clearly driven by a genuine interest and appreciation of the inherent value of traditional or African vernacular architecture; it was abundantly far from the jingoistic and racist apprehension offered by *The Architect, Builder & Engineer* and its editor. It is provocative to suggest, and certainly needs further research and attention, that the delayed interest in African vernacular architecture – as a delayed interest in Arts and Crafts precepts and principles beyond a reactionary and defensive reinscription of Englishness into the dislocating territory of the Cape – helped establish South Africa's modernist era as one that could be characterised as 'the other tradition' of modern architecture. Where the Bauhaus consumed the Arts and Crafts *efficiently* and without much thought, the delayed meal in the South African context might have opened local architectural practice to a 'soft' modernism that embraced geography, culture and local materials through a 'newly discovered' African vernacular architecture – all exactly at the time the policy of apartheid began to harden.

3 CONCLUSION

The arrival of a professional class of architects in Cape Town from England and Scotland towards the end of the 19th and beginning of the 20th century coincided with the ideological predominance of the Arts and Crafts movement. These colonial architects were primed to value vernacular architecture on its own terms but also as a resource for modern interpretation and reinvention. The Cape, and southern Africa in general, presented a pair of vernacular traditions – Cape Dutch architecture and native vernacular architecture – that discourse at the time set in contradiction to each. The local 'native' vernacular resource was not appropriated or used and discourse at the time instead aimed to discredit 'native' vernacular in favour of the original settler Cape Dutch.

It is clear that the general prejudice against 'native' architecture was born out of white supremacy attitudes – circumscribed in this instance through ideas of 'Englishness' – such that the contradictions and ambivalences in the attitudes towards these two vernaculars were papered over through jingoistic and racist discourse. The classification of objects and works into types allowed the eventual resolution of the contradiction by separation of 'native' vernacular and settler vernacular through simplified spatial configurations – round and square – rather than trying to parse what was in essence a strong homology in building materials. Ironically, the delayed valuing of native vernacular architecture in the 1940s and 1950s might have helped seed a regionalist or 'soft' modernist tradition in South Africa at the time that apartheid policies were hardening.

Despite this shift, the troubles and lost opportunities of the past persist. Toward the end of 2020, the state announced it is abandoning its 25-year-old housing programme – which had been a subsidy-driven version of the 51/9 NE house-type – in favour of a 'site-and-service' self-built housing strategy which, ironically, had also come to define the apartheid state's failing control of the country in the late 1980s (Mabin 2020: 464). What will these self-built houses be made of? Mud is banned – besides, the skills that define vernacular architecture as passed on from generation to generation have long been lost when Arts and Crafts ideologues denigrated African vernacular architecture. It is clear that the only building material at hand as part of a vernacular tradition – a building material that Delbridge (1929: 5) decried "outrages both Art and Nature" – is corrugated iron.

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History of Construction Cultures – Mascarenhas-Mateus & Paula Pires (eds)

Architecture, urbanism, construction work and local labor at the turn of the 20th century in Lourenço Marques, Mozambique

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ABSTRACT: In the last 15 years, substantial research has been conducted on architecture and urbanism in African Portuguese speaking countries, scrutinizing the introduction and influences of design and planning throughout the late 19th and 20th centuries. The social sciences literature on the five postcolonial states, especially since the 1990s, helped with investigating the legacy of these mechanisms in maintaining colonial power and knowledge post-independence. Construction history has paid scant attention to the architectural production in that context. However, much can be gained to understand when and how racialized categorizations of materials and construction technologies were introduced; and how labor involving local workers was organized. To illustrate this claim, use will be made of documentation produced by the Public Works Office from the late 19th and first decades of the 20th centuries concerning Lourenço Marques, available at the Portuguese Overseas Historical Archives and at the Historical Archive of Mozambique.

1 INTRODUCTION

"Urban built environments are spatial and material archives. Streets, buildings, open spaces, or infrastructures are registers of historical negotiations and repositories of data. Stories of power, geopolitics, economic systems, labour and culture can be revealed through road names and construction materials, portals and pediments, park benches and chimneys. Embodying our desires, needs, and resources, they condition how we live and interact with each other, and trigger countless reinterpretations and re-appropriations. Most of this dense layering is not immediately legible; it has not been decoded. Rather it is part of a more intuitive, live sense of "urbanity" that generates contemporary individual and collective senses of identity and belonging" (Lee & Misselwitz 2017, 10).

Quando nos resolveremos nós a ser modestos, para não se reparar em que somos insignificantes? (When will we settle to be modest, and begin to notice that we are insignificant?) The words of António Ennes (1946/1893, 151), royal commissionaire and mentor of administrative reform in the Portuguese province of Mozambique, at the end of the 19th century, addressing the "imprudence" of the metropole in delaying the implementation of regulations for hut tax (*imposto de palhota*) and obligatory employment of the *indígenas*. These legal instruments respectively introduced in 1892 (see Ennes 1945/1898, 502) and 1899 (Portugal 1899), effective control by the Portuguese over the existing chieftaincies inland south of the Save River, along with the establishment of administrative apparatus in the following years, subdued the local populations to the capitalist colonial system. Control had been initiated with the so-called military pacification of the land from 1895 onwards and the consequent dismantling of the Gaza empire. The result was the locals began through coercion to play the part attributed to them by the colonial project: that of taxpayer and "natural" resource (meaning low-cost/unpaid labor) (Costa 1940).

Prohibiting building in nondurable building materials within the walled precinct of Lourenço Marques (presently Maputo) after the 1875 great fire that destroyed almost half the settlement (Castilho 1880, 8), pushed the huts to the *subúrbios*. These suburbs generally were poor, formerly unauthorized occupation of the colonial map that lay beyond the municipally defined city boundaries, the location for lower income, African and *assimilados* groups. The result was the sanctioning of racial and social segregation. Not without irony, and in line with the subsequent municipality's edification guidelines (see Morais 2001, 230 endnote 86) a few decades later, the dwellers in the *subúrbios* were prevented from using perennial materials in constructing their houses – originally thin wooden skeleton structures covered in reeds (*caniço*), over time converted to roof sheets (*madeira e zinco*) and concrete block constructions. For the city dwellers, as of 1921 (Câmara Municipal – Posturas Municipais 1921, Art. 2.°, Art. 188.°, cited in Morais 2001, 229 endnote 60), the use of roof sheets

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Figure 1. Rangel, R. no date [1960s?], poor whites in the Xipamanine quarter, Lourenço Marques/ Maputo. CDFF, Collection Ricardo Rangel (Foto 61 RR/18cm).

was prohibited for the edification or rehabilitation of their residences (which existed in large numbers in the north-western part of the city, in the Alto Maé neighborhood, as well as in the suburbs). Such “a piece of urban fabric, for the narratives it encapsulates or the practices it enables” (Lee & Misselwitz 2017, 10) implied poverty and related to living in the suburbs (Figure 1). From then on masonry became mandatory for housing constructed within the city.

Ultimately, Africans were organized to living standards opportunely deemed, and acted upon as, un-urban (i.e. housed in areas lacking “proper” urban infrastructure, such as sewers, running water, electricity and roads), unhygienic and thus conveniently set apart (but, and according to the colonial understandings of labor force efficiency, housed close enough to the place of work to avoid long distance commuting); and mostly unfit to be classified a citizen/civilized, being ruled under the indigenato system until 1961 and beyond (Portugal 1961; the only exception was a group of *assimilados*, who could be tried by civil law along with the right-bearing citizenry, “*indígena*” was a legal term essentially describing individuals who lived in accordance with tribal ways). The de facto living and working conditions did not immediately reflect the new “officially established” relations between former indigenous and non-indigenous. In other words, Africans would remain subject to formalized exploitation and exclusion from a hegemonic authorized discourse that acted to validate a set of “transferred” norms and standards for urban infrastructure and built forms, which undermined alternative and subaltern practices of property ownership. These dwellers were excluded from tenure security, renting out their houses or their small land holdings in the *subúrbios* allocated by Portuguese settlers. Their everyday homemaking, their ambiences and dwellings were categorized as backward, temporary, built outside full state control and liable to elimination (Morais 2001, 149–59) as the expected ever-expanding European city encroached (and, according to state propaganda, liable to up-grade or “improvement” by assimilation of Western culture).

The conditions for urban experience were further aggravated with the implementation in 1904 of the “Regulation of indigenous servants and workers in the district of Lourenço Marques” (Portugal 1904), establishing restrictions that over time made the city inaccessible to most Africans. Accessibility was restricted to those owning property or businesses, employed in the public service, in possession of a license to look for a job (generally as unskilled day labor in the port and railways, and in domestic service in colonial settler households [Jenkins 2013, 84]), or who could provide evidence of a short-term stay to attend a personal or professional matter. Those regarded as “admissible” were prohibited (except for some professions) from circulating within the city after 9 p.m. (Oliveira 1987, 96–7). It became increasing difficult to be admitted into the city and to certain jobs. Eventually even low skilled jobs “became reserved for immigrants (predominantly “non indigenous nationals” […]) as well as a small privileged ‘assimilated class”’ (Jenkins 2013, 84, see also Zamparoni 2002). This affected their identification (*bilhetes de indentidade*), access to free transit (*passes de livre trânsito*), made it mandatory to be recruited for work and constrained circulation in the city and between neighboring administrative areas.

From the 1920s on, occupation of the unplanned areas in the vicinity of the city limits and towards the north and north-west increased consistently and intensified, structuring itself along the main roads connected to the hinterland; the exception being the Xipamanine and Munhuana planned indigenous neighborhoods. These neighborhoods were the result of isolated government actions in urban planning of the suburbs and the implementation of infrastructure (churches, primary schools, public water points, etc.). They were further associated with missionary congregations engaged in the evangelization and schooling of the indigenous population (education and health assistance were to a great extent provided by missionaries until Mozambique’s independence in 1975), through which the politics of assimilation (with little impact on the indigenous population) was mobilized (Morais 2001, 151).

Until the late 1940s, lacking cartographic data, detailed physical and related social surveys of the de facto fast-growing Lourenço Marques “African city/ *caniço* (city of reeds)” were clearly expressed in the city’s master plan (see Ministério do Ultramar

Figure 2. Rangel, R. no date [1960s?], building site, next to the City Hall building, Lourenço Marques/ Maputo. CDFF, Collection Ricardo Rangel (RR01_25_A_01).

Figure 3. Aerophotogramme of Lourenço Marques (the "city of cement" is highlighted) showing part of its subúrbios, 1968. The smaller hatched area in the subúrbios refers to the "indigenous" planned neighborhood of Munhuana. AHM, Collection Arquivo da Câmara Municipal de Lourenço Marques (Icon. 4690, Arm. C, Prat. 2, Cx. 56).

1952). These were prepared in the metropole by the Colonial Urban Office, subsequently named the Overseas Urbanization Office in line with major reconfigurations concerning the overseas provinces' legal status which contrasted with the post-1945 United Nations' new world order on decolonization. This plan, which took nearly a decade to see completion (completed 1952, approved 1955), quickly became obsolete due to its ignorance of the rapid socio-economic and physical transformation of the area, which stimulated land speculation and illegal development. The Six-Year Plans for Economic Development, launched in 1953, with huge investment in infrastructures, urban planning, and building, along with favorable economic conditions, created important opportunities for the increasing European population triggering private investment and a large number of real estate operations. The modernization effort led both by the colonial state and by private investment endorsed a modern and modernist architectural practice in the main cities (especially in the capital city Lourenço Marques and in Beira, the colony's second city). The practice clearly invokes the connection of these products to their actual condition of production (Figure 2), i.e. conciliation of "the apparent paradox […] of the application of the modernist movements' ideals of progress and democracy" to the wider colonial framework (Domingos 2015, 241).

The *subúrbios*, in contrast (which were not accepted as urban and became a locus for "tolerated" illegal construction), remained largely on the sidelines of this "modernization", revealing the practical limits of colonial development policies and its (deceptive, racialized) discourses. The city population continued to grow at historically high rates as a result of inward migration from the southern Mozambique region and continued significant immigration from the metropole. The planned residential areas densified and quickly became a focus for high-rise speculative development. Population growth was also visible in the suburbs, which became overcrowded, and the city began to expand into the existing unplanned areas (Figure 3) (Jenkins 2013, 89). The population living in the core of the locally dubbed *cidade de cimento* (city of cement, city built to European standards) was increasingly housed in apartments, but lower-income, African and *assimilados* groups were housed in precarious conditions in the rapidly growing, densely occupied unplanned areas (see Guedes 1963).

If we take into consideration that hygiene and moral issues were consistently used by the Portuguese colonial administration to justify racial segregation, then stipulating non-resistant materials for housing construction and lack of infrastructure (sewers, and running water) as adequate for the non-European neighborhoods, forced the non-European population to play a perverse game of which they could not master the rules,

"Parece-nos absolutamente inútil e um desperdício estabelecer canos ao longo das ruas habitadas por asiáticos e africanos ou por população que nunca terá em suas casas uma torneira do abastecimento das águas. (It seems absolutely useless and a waste [of resources] to implement a water [and sewer] system along roads inhabited by Asians and Africans or by population that will never have running water in their houses) (Terra Viana 1907, 54).

Discriminatory decisions included banishing *indígenas* from schools located within the central areas of the city from the 1920s, restricting them to separate, less sophisticated, facilities (see Zamparoni 2002, 474); establishing separate residential areas and a dual planning system (see Aguiar 1952); and maintaining distinct access in multistorey buildings by having segregated entrances for African servants.

Before the 1930s when, with the establishment of the Estado Novo dictatorship, free press would cease, African newspapers of the early 20th century openly criticized this state of affairs and the neglect to which the African population was condemned, especially

Figure 4. Rangel, R. no date [1960s?], suburban housing. CDFF, Collection Ricardo Rangel (RR01_29_G_02).

regarding education and access to proper jobs asking, "*poderá Portugal dizer que veio para a África para civilizar*?" ([after all this] can Portugal say that it came to Africa to civilize?) (*O Brado Africano* 16 February 1924, cited in Zamparoni 2002, 475).

In the last 15 years, a substantial amount of research has been conducted on architecture and urbanism in African Portuguese speaking countries, scrutinizing the introduction and influences of design and planning throughout the late 19th and 20th centuries (see, for instance, Fernandes et al. 2006; Jenkins 2013; Morais 2001; Silva 2015). The social sciences literature (and particularly postcolonial studies) on the five postcolonial states, especially since the 1990s and building on a substantial colonial archive, helped us investigate the legacy of these mechanisms in maintaining colonial power and knowledge post-independence (see, for instance, Cabaço 2009; Domingos 2015). So far, the field of construction history has paid scant attention to the architectural production in this context. However, the few publications on the subject suggest that a lot can be gained by trying to understand when and how a racialized categorization of new building materials and construction technologies was introduced, and by whom; or how labor involving local workers was organized, pushing us to think about the agency of African laborers and the specific modes of production underlying this particular built legacy (Craenenbroeck & Lagae 2015).

I argue that formulating responses to such questions provides ample insight to write a (partial) history of architecture of the 19th and 20th centuries in Mozambique, through a construction and social history approach. To illustrate this, I will discuss reports and correspondence concerning Lourenço Marques produced by the Public Works Office of Mozambique to the Portuguese Ministry of the Navy and Overseas Territories, available at the Portuguese Overseas Historical Archives (Arquivo Histórico de Mozambique [AHM]) and at the Historical Archive of Mozambique (Arquivo Histórico de Moçambique [AHM]).

1.1 *Physical urban development and architectures of discrimination in the turn of 20th century Lourenço Marques*

The growing economic and political importance of Lourenço Marques, subordinated to the interests of South African mining capital, called for expansion of the city, which was also associated with the development of its freight port and railways, with a view to the transit of goods and labor (Bethencourt & Chaudhuri 1998, vol. 4, 90-1, 174–5, 191–2; Jenkins 2013, 81ff). The city's expansion project, executed by the 3rd Section of Public Works between 1887 and 1895, focused on two imperative issues: greater accessibility for intraregional and regional trade and sanitation of the town (Franco de Mendonça 2016, 92). Construction work on this project began with filling the swamp next to the walled settlement with an average 2m of infill. This operation enabled the establishment of a series of longitudinal avenues parallel to the waterfront and to the major axis of the "new city", the Avenida D. Carlos (built over the former boundary road), with spacing of roughly 100 to 200m, connected by ten transverse avenues (Obras Públicas de Lourenço Marques… 1888). These roads were built on land fill and at least 2/3 of the volume of land needed for that purpose came from the elevations surrounding the plateau north of Maxaquene cove, to the east end of the city (Obras Públicas de Lourenço Marques… 1888). A network of collecting ditches at the base of the Maé and Maxaquene slopes in the solid ground north of the old settlement allowed collection of water from the numerous springs that, together with the tidal water, fed the swamp (Terra Viana 1907, 14). Water collected from these springs fed the public fountains in the city, which were used (mostly by the settler population) until the first decade of the 20th century when the regular supply from the Umbeluzi River was established (Terra Viana 1907, 14–5). Phased sanitation works in wetland areas and the planting of eucalyptus in the vicinity of the swamp and along the new roads continued until the first decades of the 20th century, with the lowland avenues next to the old settlement continuously flooded by water that flowed freely on its surface due to the lack of a sewer system (Galvão 1920, 18–21; Soeiro 1895; 5, 7; Terra Viana 1907). Several projects to deal with the sanitation infrastructure of the area were delineated over the years by public and private entities and postponed by the competent authorities (see Terra Viana 1907). The city was considered insalubrious mostly due to the usances of its inhabitants and of those daily visiting Lourenço Marques in large numbers, who, until the turn of the 20th century, continued to use the close shore and swamp as latrine. Many households had to resort to septic or movable tanks that were periodically dumped directly into the sea near Ponta Vermelha, or to open pit latrines, and the subsequent city's sanitary sewage flow also into the Bay with no filtering or treatment (Terra Viana 1907). By 1891, the city had a population of 2285 individuals, increasing by 1904 to 9849,

Figure 5. Plan of Lourenço Marques showing the *Foral* (town land registry) area, which comprised all land within a 2km radius from the central square (Praça 7 de Março) including the Ponta Vermelha township, to the east, on the Polana headland [1910]. The plan also registers the water supply network, the streetcar network under construction, the proposed reclamation area in the Maxaquene cove and the area already occupied by edification (indicated by the shading). BN, cartographic material (cc-53-p2). Available at: http://purl.pt/21979 (Accessed :17 December 2020).

which comprised 4961 Europeans, 1690 Asians and 3468 Africans (Terra Viana 1907, 15).

Infilling work next to the old settlement was carried out using African labor and Decauville material (Obras Públicas de Lourenço Marques ... 1888). The rubble was carried down the slope to the marsh in wagons on iron rails that were then pulled by human traction up the slope to be loaded once again (Direcção de Obras Públicas de Lourenço Marques 1888). Due to the lack of manpower and given that "[…] everywhere the land was being excavated to open avenues and streets and to build houses […]", the Police Corps was also recruited for this construction work (Repartição de Obras Públicas da Província de Moçambique… 1888, trans. by the author). The city's new urban venture, however, was confronted with several financial and technical difficulties. The leasing of a large quantity of the land concerning the planned area of intervention, forced the government to pay heavy compensation (Direcção das Obras Públicas de Lourenço Marques 1888). The Public Works Office, engaged in various improvements in the city (piped water source, sanitation of the marshlands that separated the old settlement from the Maxaquene hillside, construction of the roads delineated in the aforementioned city's enlargement project, as well as the maintenance work of several public buildings) complained about the lack of construction materials (both lime and timber came from other districts, while most construction materials were imported; quarried tuff stone from the Ponta Vermelha headland and lime from oyster shells being the most common materials used in ordinary masonry in earlier permanent buildings) and specialized workers (master builders, craftspeople, etc.), being as they were limited to African masons (available in quantity) for the most common jobs and a few skilled Chinese carpenters (Castillho 1880; Direcção das Obras Públicas da Provincia de Moçambique 1894, 1895). The number of technical staff at the 3rd Section of Public Works (with only a few military engineers), and in the overall remaining province, was also very small when compared with Angola or Portuguese India, being the object of complaint in several reports by the Public Works directors. According to these reports, European laborers did not cope well with the local natural environment (high rates of marsh fever were observed) and the struggle to recruit auxiliary personnel (master builders, toolmakers, etc.) was constant. Europeans could not live with the modest salary allocated for those classes (Direcção das Obras Públicas da Provincia de Moçambique 1895). Construction materials were much more expensive in the district of Lourenço Marques (compared to the remaining province), and the same applied to the workforce. The slow progress of sanitation improvements, the lack of a sewer system, proper piped water system and paved roads were considered causes of the city's insalubrity and lack of edification in areas outside the old settlement where these improvements were lacking (Repartição de Obras Públicas da Província de Moçambique 1888; Direcção das Obras Públicas da provincia de Moçambique 1895, 1901). Procuring public investment to macadamize the roads was considered a main priority by the Public Works, since the difficulty of transporting construction materials to building sites on roads open to heaps of sand and thickets of greenery was a major source of discouragement for private real estate operations, preventing the city's growth (Direcção das Obras Públicas da Província de Moçambique 1901). Unpaid and obligatory work by the indigenous people through conscription was considered sufficient to build the few roads that remained to be built between villages in the district. By 1900, an average of twenty houses per month were built in the city, of which about one quarter were in masonry (Direcção das Obras Públicas da Provincia de Moçambique 1901). In addition to the old settlement, the edification in the new city blocks was limited to the area between the Avenues Augusto de Castilho (presently Vladimir Lenin) and General Machado (current Guerra Popular) (Figure 5). The built area continued to the north-west, in Alto Maé, however, the presence of marshy areas to the west of the Alto Maé Headquarters well into the 20th century devalued this neighborhood, being considered unsanitary, and thus inhabited by the less privileged classes (Galvão 1920, 21).

The Public Work reports (Direcção das Obras Públicas da Província de Moçambique 1894, 1895) shed light on a number of realities linked to building in late 19th century Mozambique (and beyond), providing lists of workers (both "*Europeus*" and "*indígenas*"), their professional category and for each one details of the number of days worked, while indicating the salary they received. They also provide us with ample documentation to investigate what “development”, “civilization” and “modernization” meant in the context of construction of the expansion of the city of Lourenço Marques and of its new buildings at the turn of the 20th century: city plan drawings; architectural drawings; lists and descriptions of materials to be used, mentioning their origin and respective costs in the three Public Works Sections of the province (Mozambique, Quelimane and Lourenço Marques); sewer network projects accompanied by commercial brochures for all kinds of components or technical assistance (from foreign companies mainly located in England and South Africa) and budgets; series of photographs documenting building sites; telegrams between the directors of Public Works and decision-makers in Lisbon concerning technical or budget-related questions, etc. Analyzing these documents against the contemporary legislation for edification and labor can help broaden our understanding of the shaping of the social, racial and built environments in Mozambique. Moreover, these documents can suggest answers to particularly challenging questions such as: To what extent did the transfer of knowledge on specific materials (prefabricated components, bricks, concrete, etc.) and building technologies from Europe and South Africa to Mozambique require a specific kind of skilled labor? How was the necessary local workforce to complete such diverse tasks on the building site recruited? How was the building site organized? How did African construction workers react to new technologies and in what way did these new environments impact on their own urban experience? How did they capitalize on that experience afterwards?

Preliminary reading of Mozambique Public Works reports and correspondence at AHU as well as a close analysis of iconographic material at the AHM and at the CDFF have already allowed some useful insights that encourage a more in-depth investigation of the impact of the transfer of materials, building technologies, organization of local labor force, and legislation for edification, on the construction of racialized spaces and subjects. Investigating such labor and construction sites opens new lines of enquiry for writing a history of the built environment.

LIST OF ACRONYMS:

AHM: Arquivo Histórico de Moçambique (Historical Archives of Mozambique), Maputo, MZ

AHU: Arquivo Histórico Ultramarino (Overseas Territories Historical Archive), Lisbon, PT

BN: Biblioteca Nacional (National Library), Lisbon, PT

CDFF: Centro de Documentação e Formação Fotográfica (Documentation and Photographic Training Centre), Maputo, MZ

DGU: Direção Geral do Ultramar (Directorate General of Overseas)

MÇ: Moçambique (Mozambique)

SEMU: Secretaria de Estado dos Negócios da Marinha e Ultramar (Secretariat of State of the Navy and of the Overseas Affairs)

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History of Construction Cultures – Mascarenhas-Mateus & Paula Pires (eds)

Transparent acrylic constructions before and after 1950 – from the 1935 Opel Olympia to the 1972 Olympic roof

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ABSTRACT: This paper looks at the historic developments that led to the use of transparent acrylic construction elements from the 1950s onwards. The analysis is based on archive material from the record group Röhm of Evonik Industries AG, the Deutsches Museum (DM), and two key objects: the Opel Olympia (1930s) of the DM and the roof of the Olympic sports facilities (1970s) in Munich. In terms of their construction, usage, and meaning, these objects show the main differences between transparent acrylics before and after 1950. For the Opel, the polymer poly(methyl methacrylate) was thermoformed, showcasing German technological innovations for propaganda purposes. In contrast, the Plexiglas© for the Olympic roof contains several additives, including flame retardant and UV-absorber. It was biaxially stretched and cold formed into aluminium frames. Expressing the democratic ideals of an open society, acrylics presented a progressive, forward looking architecture of seemingly light structures.

1 TRANSPARENT ACRYLICS – PRODUCTION AND MEANING

In Germany, sheets of transparent acrylics have been produced since the 1930s by the company Röhm & Haas but have only served as construction elements in architecture since the 1950s. The reasons for this derive from the composition of the materials and the production technologies. Only beginning in the 1950s did the technological developments progress far enough for pieces using transparent acrylics to meet construction safety standards. Besides this technological progress, there could be other factors that pushed the development of transparent acrylics as a building material. The iconography of the material and its meaning has changed over the years. This paper demonstrates how transparent acrylics were consciously used to convey political, social, and cultural ideas.

Acrylics are fully synthetic plastics that were discovered in the period between the World Wars (Waentig 2008, 25). At that time, polymer chemistry had only recently been accepted. Natural caoutchouc was scarce and many synthetics were developed in the search for a substitute (Trommsdorff 1984, 225). Most only reached the stage of industrial production and market maturity in the post-war period (Mark 1982, 4–5). However, in the case of poly(methyl methacrylate) (PMMA), similar products had been developed in the 1930s by Imperial Chemical International ICI in the UK, as Perspex©, by Röhm & Haas GmbH in Germany as Plexigum© and Plexiglas©, and in the USA by Rohm and Haas as well as by Du Pont. The paper at hand mainly focuses on the Plexiglas product from Röhm as the company was market leader in Germany and many other European countries.

Transparent acrylics had early on become a promising material for new inventions, seen as progressive, fascinating and decorative. Though jewellery and household articles, e.g. cutlery, were produced, acrylics were not available to everyone. The material was quite expensive at the beginning and rather exclusive, adding a touch of luxury (Buchholz 2007, 18). Products made of transparent acrylics, such as musical instruments, spectacles or engravings were very impressive at the beginning. The glass-like fragile and immaterialized aesthetic contradicts the organic shape of the thin but very stable material. At the time, the material seemed to withstand all known physical laws (Bulk 2018). Its outstanding qualities made acrylics superior to other transparent plastics or mineral glass. The refraction index of acrylics is very close to that of mineral glass, and acrylics exhibit good impact resistance as well as having a smooth surface, good infra-red absorption, light in weight, and excellent ageing properties. Acrylics remain stable without colouring changes for a long time and, when breaking, they produce no small particles, thus the perfect material for vehicle windows (Vieweg & Esser 1975, 191). Transparent acrylic sheets consist mainly of the organic polymer PMMA. Small quantities of additives change the formula, which together with the production techniques, influence the mechanical and chemical properties of the end product (Babo et al. 2020).

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Figure 1. Forming of a strongly bent acrylic glass sheet for an omnibus window on a steel mold covered with cloth and a wooden pressure frame in the 1950s. Measurements of the window sheet: 1100 x 1100 x 5 mm, weight 7 kg (Röhm & Haas GmbH (ed.) 1965, 15).

2 1933–1945: BEGINNING OF PRODUCTION, PROPAGANDA AND THE ARMS BUILDUP

The history of the transparent acrylic sheet began in 1928 with the product LUGLAS. This safety glass was made of two sheets of mineral glass, glued together with sticky acrylic resin. Such a construction element could prevent the heavy injuries caused by the sharp edges of broken mineral glass, and was used for car windows, e.g. the Mercedes Benz of Reichs President Hindenburg from 1928/29 (Röhm GmbH 2007, 33, 40). Nitro cellulose, which had previously been used, yellowed quickly after production and was very stiff in contrast. Methyl acrylates were permanently sticky and did not yellow at all (Trommsdorff 1984, 214).

After the discovery of methacrylate in 1931, further improvements of the production technique were necessary, especially the careful management of the manufacturing temperature, to enable products completely made of PMMA to appear in 1933 (Trommsdorff 1984, 225–233).

Sheets and blocks were produced by polymerization in chambers that could be heated and cooled with water at different times during the process. Prepolymerized methyl methacrylate (MMA) was poured between two sheets of mineral glass. Thin and flexible walls were used to seal the mold. During curing and polymerization, the acrylate shrinks. Therefore, a water bath was used to cool the PMMA and the water pressure helped to press the mold onto the PMMA. After removing the glass mold, the result was a clear, solid transparent sheet without flaws (Röhm GmbH 2007, 37).

In a second step, after curing, the flat sheet could be transformed into a different shape by either melting the thermoplastic material over a mold at 70 to 155°C, depending on the thickness, or by pressing the warm and flexible sheet onto a steel mold (Figure 1).

In this way, the side and overhead windows for buses and the front windows for racing cars were produced in the 1930s, enabling new car designs in streamlined shapes with bent windows (Figure 2, Röhm GmbH 2007, 39–41). Bus windows became the first construction pieces produced in a wider range (Trommsdorf 1984).

Since 1936, such acrylic sheets were produced industrially. These "organic glass sheets" were lighter than mineral glass and had further enhanced safety qualities than LUGLAS had displayed.

In 1936, the chemist Otto Röhm, one of the founders of the company Röhm & Haas and co-developer of Plexiglas, presented the product at the main meeting of the German Chemists' Society, "Hauptversammlung der Gesellschaft Deutscher Chemiker". In 1937 Plexiglas was internationally presented at the World Fair in Paris, where it won the Grand Prix and a gold medal for "arts et techniques". Henceforth, Plexiglas became synonymous for acrylics and was acknowledged as a material for many special applications despite its first appearance as a surrogate for glass (Röhm GmbH 2007, 42).

The examples in this chapter demonstrate how transparent acrylics helped convey the ideas and objectives of the political leadership. Acrylics combined transparency and easy handling, which was used to showcase the function of machines and thus technical superiority.

In the 1930s, many exhibitions took place in Germany for the purpose of propaganda and as advertisements for the National Socialist regime. One of them was the „Schaffendes Volk" exhibition in Düsseldorf in 1937, which featured several products made of Plexiglas, among them a giant globe (Haas A.G. & Röhm 1938). Two further exhibitions were the International Automobile Exhibitions in Berlin in 1935 and 1939, as well as the automobile and motorcycle exhibition in 1937. In each of these events the Opel Olympia (Figure 3) was exhibited as one of the first mass produced cars (Vaupel 2011). Its name refers to the Berlin Olympic Games of 1936. The exhibit sign, "Das Olympia-Modell aus Plexiglas", also implies how proudly the Plexiglas material was presented.

The roof, trunk, doors, cowling, and seats of this exhibition model were built in transparent Plexiglas to visualize a technical novelty, the construction of the monocoque. This unitized body was a self-supporting coachwork and consisted of a supportive skeletal structure that integrated the chassis. In this way, no separate frame or chassis were needed and the total weight could be reduced. The construction process resembled that of an airplane but was an innovation in the automobile industry. The acrylic sections of the coachwork were produced as a flat sheet as described above. Afterwards, the sheets were heated, formed over moulds, cut, and the holes for the screws were drilled. The construction elements were screwed onto the car's metal framework without a buffer. These could have not been produced so easily, as thin and light, with the same effect and transparency, in mineral glass.

The PMMA material was consciously deployed to demonstrate the power of mankind over material. It also served the autarkic aspirations of the regime. The water like methacrylic compounds were extracted in

Figure 2. Examples of transparent Plexiglas windows in the 1930s by Röhm & Haas, applied to cars, buses and airplanes (Röhm & Haas A. G. 1936, 10).

Figure 3. Opel Olympia, DM, presumably a later replica from 1937, produced by Adam Opel GmbH, Rüsselsheim (Deutsches Museum, Munich, DMO, Inv.-Nr. 1977–1210. Photo: K. Mosch).

four steps from “heimischen”, domestic raw materials such as wood, charcoal, and chalk (Haas A.G. & Röhm 1938). Transforming opaque and rigid materials into something transparent and pliable, acrylics crossed boundaries previously seen as insuperable.

In their industrial report after the end of the war, the Allied forces stated about Röhm & Haas A.G.: “In the field of research, they have been progressive and enlightened and have devoted more time to fundamental work than many German companies. The work […] on block polymerization is a valuable contribution and may well be only a small part of the research team’s activity” (British Intelligence Objectives Sub-committee, 1945–46, 13).

Figure 4. Front cockpit with gun outlet of the He 111 H16, a standard German Airforce bomber during World War II, built after 1937. DM München, Inv.-No. 79339 (Deutsches Museum, Munich, Archiv, CD64549).

3 AFTER 1945: DEMOCRATIZATION AND ARCHITECTURE

After the war, quite the contrary to the progress in the plastics industry, architecture and design in Germany were out of step with international developments. In contrast to the buildings of the previous two decades, and in accordance with westernization and Americanization, the international style in architecture was re-integrated in Germany. The architectural style of the 1950s focused on the expression of materials and their mutual contrasts (Nerdinger 1990, 42). New building materials such as acrylics and cement asbestos were used widely.

The architectural trend for modern flat roofs with a brightly lit interior led to a widespread application of transparent acrylic *cupolae*. The designs incorporating light openings on a flat roof were copied from international examples from the 1930s (Adlercreutz et al. 2009, 34–37). The round or square shaped *cupolae* were the first mass produced building elements made of transparent acrylics (Figure 5).

Cupolae were mainly produced by means of thermoforming with high molecular PMMA, which is the preferred material for a high-quality standard. The polymer was produced from sulfuric acid, methane, ammoniac, acetone, and methanol. These were obtained from domestic gas, cracked gas, or brown coal in four steps (Röhm & Haas GmbH 1957, 15). High molecular PMMA cannot be processed by means

Figure 5. Roof of the Stadtsparkasse Darmstadt of 1957 with two types of square shaped *cupolae*, single layer, screwed onto the funnel (Röhm & Haas GmbH 1957b, 32).

of extrusion or injection molding (Röhm GmbH 1976). Therefore, a sheet is first cast and afterwards either warmed and pressed into a mould or blow moulded with hot air. Because of the high degree of stretching, the molecules are orientated biaxially, thus improving the properties of the material. This orientation varies to different extents depending on the shape of the product, and is higher on top of the *cupolae* than on their rims.

The *cupolae* were improved over the following years by switching from single to double partitions, thus improving their insulating qualities, and by adding mechanical and electrical features, e.g. overturning, openings, and others. The largest *cupolae* in Europe at the time was built for a kindergarten in Aachen, measuring 7.5 m in diameter and consisting of several, double-layered parts (Saechtling 1972, 352).

In 1952, the mass production of corrugated Plexiglas XT began (Röhm & Haas GmbH 1952b). The extrusion production technique allowed for long, flat, and corrugated sheets for roofs, balustrades and others. For extrusion, low molecular weight PMMA is suitable as it exhibits better flow properties. Granulated PMMA is continuously trickled into an extruder screw, where the thermoplastic material is warmed, melted, and transported forwards towards the outlet. The shape of this outlet determines the fixed cross-sectional profile and the width of the outcoming sheet. The sheet cools on a conveyor and is endless with its length determined by cutting (Vieweg & Esser 1975, 468–475). Cast or injection moulded acrylic products are favourable because of their relatively low production costs. Also, bigger sheets can be produced and there is little to no crack propagation in case of damage (Röhm & Haas GmbH 1952a, b).

Extrusion further enabled architecture to include light and create luminous facades. Corrugated sheets dominated the cityscape of the post-war decades, mainly as roofs or balustrades for balconies (Figure 6).

In 1955, Röhm was producing flat sheets with sizes of up to 4 square meters and of 0.7–12 mm thickness. Three different corrugated profiles sizes were offered, two of which corresponded to standardized panels made of asbestos cement and corrugated metal. At first, mainly colourless and transparent Plexiglas was produced. Corrugated sheets also came in a translucent white. The surface was plain and glossy and some were structured. Soon, the colour palette included red, green, yellow, and fluorescent (Haas A.G. & Röhm 1955).

Figure 6. Extruded corrugated transparent *Plexiglas* roof of a gas station at the Technische Hochschule, Darmstadt 1957 (Photo: Evonik Industries AG, Corporate Archives, Record Group Röhm, Photo Archives, Hanau).

The benefits of polymer stretching were known from the production of fibres and films. The molecules in an organic polymer in a relaxed state are usually disorderly, amorphous, and tangled. Under heat, thermoplastic polymers can be stretched mono- or biaxially. The ideal extent of stretching to gain the best properties is up to between 70 and 80 % for acrylics. In the process, the molecular chains of the polymer are ordered almost in parallel into a crystalline structure. As a consequence, compared to cast acrylics, stretched acrylics have greater toughness and stability as well as a higher resistance to breakage, corrosion, and weathering. Stretched sheets have lower elongation at the break, crack propagation, and a tendency for micro crazing, and correspondingly installed where very stable acrylics are needed (Schreyer 1962).

Sheets of less than 2 mm thickness can be treated cold and cut by means of metal shears, punched, or even nailed. Stretched sheets can be pressed in a frame under tension while bending, as they are two to three times more flexible than cast acrylics (Röhm GmbH 1971, 8, Schreyer 1962). Strongly shaped construction elements such as *cupolae* cannot be manufactured from stretched sheets but partially contain the qualities of stretched material. The warm treatment of stretched sheets is possible in a frame that prevents the sheet from reverting back to its original, flat shape (Vieweg & Esser 1975, 575–577).

The most famous example of construction with biaxially stretch-formed acrylics is the roof of the Olympic sports facilities in Munich, built in 1972. The tent shaped roof consists of a metal framework. The acrylic sheets are attached onto a net of steel wire like a skin (Figure 7). The translucent products used by Röhm were stretched Plexiglas GS 215, colourless and grey 816 at 4 mm thickness apiece. The latter was used to protect visitors from the sun.

All in all, about 10,000 sheets form the roof, consisting of hyperbolic paraboloid shapes, designed by

Figure 7. Olympic roof under construction. Acrylics are already mounted onto the buffers of the steel thread net. In the next step, the chloroprene rubber sheets are pressed around the edges and fixed with an aluminium frame and screws (Front cover of a greeting card with advertisement and stamps on the occasion of the Olympics 1972 from Knoll AG Ludwigshafen, unknown photographer, private property S. Brunner).

engineer Frei Otto and architects Behnisch and Partners. Each sheet covers a size of up to 3 by 3 m and was biaxially stretched from a cast sheet measuring 175 by 175 cm (Figure 8; Madsack 2010, 283).

The construction had to be flexible because of the wind, snow loads and the thermal expansion of the acrylics. Therefore, an elastomer material was used for construction in direct contact with the acrylics, black chloroprene rubber buffers and sheets (Figure 9).

The acrylic sheets were cut to different sizes and installed with up to 16 buffers per sheet onto the wire net. Every sheet had an individual aluminium frame. Between one frame and another, a rubber band was installed underneath. In addition, two aluminium bars on top connected the frames, each with up to two bars per side (Figure 10). Hence, a total area of about 80,000 m^2 of Plexiglas was created, which cost about 6m Deutsche Mark at the time, corresponding to about 9.7m euros today (Röhm GmbH 1972a, b).

The material had to be translucent because the Olympic games in Munich were the first to be broadcast in colour television, requiring a lot of natural light.

The decision for Plexiglas over other polymer materials such as the more impact resistant glass fibre, reinforced Polyester, was finally made by the Olympia-Baugesellschaft mbH because of PMMA’s fire behaviour. In a fire, the stretched sheets of Plexiglas will shrink and the heat and smoke of the fire can dissipate. Plexiglas burns without dripping or toxic gasses. It is classified flame resistant class B1 according to DIN 4102 because of an added flame retardant. To protect this additive, a UV-absorber was also added to the formula (Institut für Bautechnik 1984, Vieweg & Esser 1975, 134–138).

The design of the 1972 Olympic Games venue was quite contrary to the architecture of the last Olympic stadium built in Germany in 1936 in Berlin. Instead of a massive stone stadium on a paved square, the architecture of 1972 seemed light and weightless, not least because of the materials used.

The material signified not just technological progress but freedom and the aspirations for an open society. The architects themselves wanted to create “an architectural landscape which encompassed the diverse forms dictated by purpose. The roof covering the athletic buildings is […] of singular character and stands as the focal point […] as seen from any distance […]. Here […] beats the heart of the Olympic Games; it is the place where the athletes of the world, the spectators and the citizens of Munich can meet” (Architects Behnisch & Partners 1969, 2).

Figure 8. Left: Biaxial stretch forming of cast Plexiglas at Röhm & Haas in Darmstadt in 1970. Middle: First sheet for the roof in 1971. Right: Construction site, transport onto the Olympic roof in 1971 in Munich (Photos: Evonik Industries AG, Corporate Archives, Record Group Röhm, Photo Archives, Hanau).

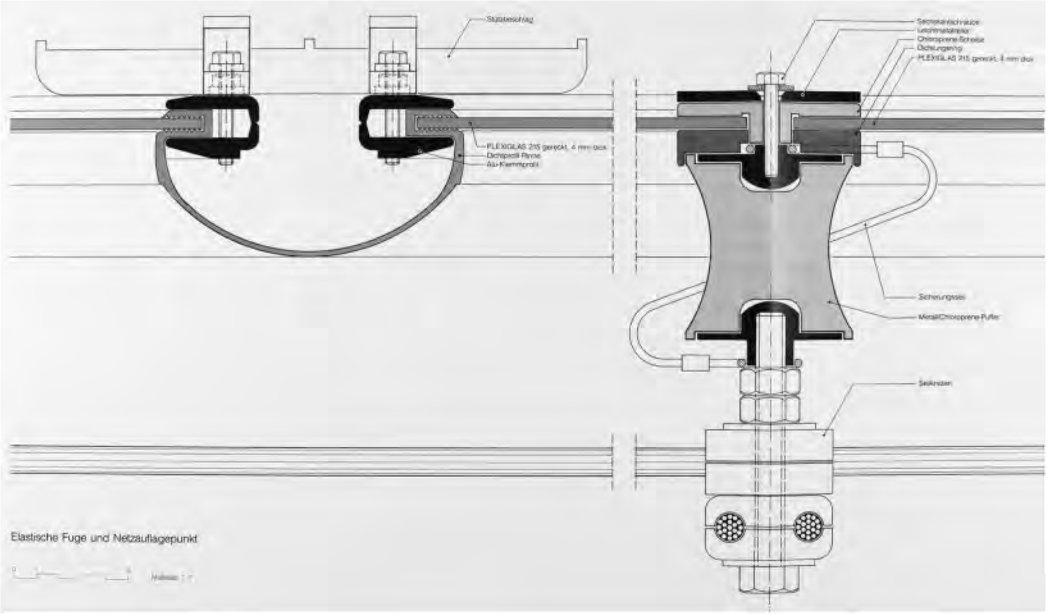

Figure 9. Cross section of the Plexiglas construction elements and their conjunction on the Olympic roof (Röhm GmbH 1989:2, 2.c.2).

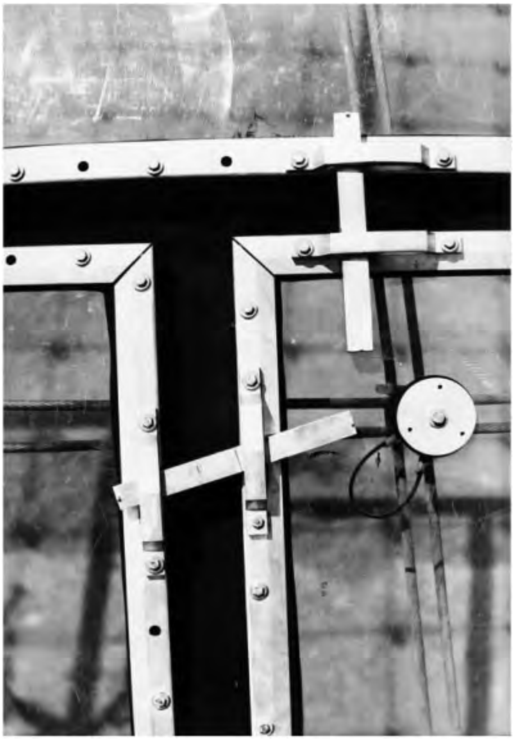

Figure 10. Conjunction of the Olympic roof elements from 1971, view from above (Photo: Evonik Industries AG, Corporate Archives, Record Group Röhm, Photo Archives, Hanau).

4 CONCLUSIONS

The factors responsible for the development of architectural construction elements made of transparent acrylics from the 1950s onward in Germany extend beyond the formulae of acrylics or production technology. Social needs, political circumstances and cultural changes also led to a new perception of the material that enabled it to be applied in architecture. Transparent acrylics were used intentionally to represent ideas of social transparency and an open society, thus attributing them a new meaning.

The comparison between the two key objects, the Opel Olympia from 1935 and the Olympic roof of 1972, points to an alternative significance of this material at different times. At first sight, the transparent acrylics from the 1930s and the 1970s seem to be exactly the same: transparent, organic glass. Plus, both make impressive, aesthetic, fascinating, and innovative use of the material properties of PMMA. However, on closer inspection, the composition of the materials is rather different, as well as their production technique: pure cast acrylic sheets that were thermoformed over a mold in the 1930s stand in contrast to the cast and biaxially stretched sheets of the Olympic roof of 1972, which include various additives in their formula, e.g. fire protection and UV-adsorbers. The latter are impact resistant and fire proof and thus fulfil the fire prevention regulations and building standards of the time.

Production techniques were developed and supported by public funding in the 1930s because the arms build-up necessitated innovation and the government supported development and research into improvements. As a result, production was also limited to windows primarily for fighter jets and bombers. Still, showpieces such as the Opel Olympia in 1935 proved that Plexiglas held utility for far more than safety glass windows. The new and fascinating, easy to process, glass-like material was used by the National Socialist regime for propaganda purposes to showcase German technological innovations with the clear intention of claiming the material as an achievement of the new political order.

On the other hand, from the 1950s onwards, first extrusion and then stretch forming led to impact resistant, transparent, and lightweight products for roofing. The enhanced fire protection qualities added in the 1970s enabled their use in architectural projects such as the Olympic roof in Munich. The Olympic roof of 1972 sets a conscious counterpoint to the massive building style of the Berlin Olympic stadium of 1936. The organic shape of the construction that spans over several buildings and connects them with the landscape, was to signify a free and democratic way of living. This message is enabled through and associated with transparent acrylics.

The cultural significance of transparent acrylics in other countries has yet to be examined and results may vary in comparison to the results of this paper.

Learning about the historical meaning of transparent acrylics and the differences in the historic chemical formulae, as well as their production techniques, helps to reassess the material. In contrast to the Opel Olympia, which is stored in a protected indoor environment, the Olympic roof is exposed to harmful outdoor influences such as UV-light, water, etcetera. In 1998, the roof was replaced, and the question of its conservation has arisen again recently. The historical significance of the material is a clue to its conservation. Knowing the history of the technical production processes of transparent acrylics makes it easier to classify the material by sight and to date the construction elements. Historic plastics are not at all the ordinary throw-away-products we mostly regard nowadays as an environmental problem. Constructions using transparent acrylics were new and sensational in their time. To showcase innovative materials and to create fascinating objects was more important than durability. Today the conservation of polymers is a challenging task of growing urgency.

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Thematic session: South-South cooperation and non-alignment in the construction world, 1950–1980s

History of Construction Cultures – Mascarenhas-Mateus & Paula Pires (eds)

Mostogradnja and Yugoslavia in Iraq: A bridge on the Euphrates near Fallujah (1964–1967)

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ABSTRACT: Among the large construction companies that characterized Yugoslav modernization after WWII, the Belgrade-based “Mostogradnja” occupies a central role in the country’s international success in the non-aligned sphere. Unlike the better known “Energoprojekt”, it was primarily an engineering company, highly qualified and economically competitive, specialized in large-span structures. Its organization, international success and specialization are discussed in the paper through the case study of a prestressed concrete bridge over the Euphrates (Fallujah, 1964–1967).

1 INTRODUCTION

The aim of this paper is to analyze – through the case study of an infrastructural project – the process by which economic and technological transfers took shape between two member states of the newly formed Non-Aligned Movement (1961). This was the first commission that an important Yugoslav construction company received abroad, obtained thanks to a winning proposal for a competition launched by a country that had, from 1958, been undertaking the process of decolonization. While the technical and economical aspect of the winning solution reflects, on one side, Yugoslavia’s emerging know-how in the field of prestressed bridge construction, and, on the other, the availability of construction materials and the climatic conditions in Iraq, the success of the project can only be understood through the geopolitical context of the 1960s and the growing economic relations between the two countries.

2 THE BRIDGE IN FALLUJAH

On the highway that runs from Baghdad in the direction of western Iraq towards Syria and Lebanon, near the town of Fallujah, there stood a narrow single-lane bridge over the Euphrates River, made of a reticular steel structure. As well as posing a hindrance to increasing vehicular traffic volumes, due to its very low inferior edge, the bridge also posed a severe limitation to further upstream navigation, especially for tug-drawn oil barges, which were forced to stop at the river port in Fallujah.

In 1961, the Ministry of Transport of the Republic of Iraq signed a contract with the renowned English engineering company, Rendel, Palmer & Tritton, (London) for the preparation of a tendered technical study for the project of a new automobile bridge. A wider bridge (with two lanes and two side pedestrian crossings) with a clearance of 6.25 meters above the river’s average maximum level was required.

Figure 1. The Bridge over the Euphrates in Fallujah, Iraq (1964–67). Source: Aćić et al., 2012, p.148.

The tender prescribed a series of obligations, based primarily upon English standards (there were no official Iraqi standards as yet), related to loads and the manner of execution of the works. Specific instructions regarding the shape of the new bridge and its construction typology dictated that it was to be a steel structure with six spans. However, the tender left applicant construction companies the freedom to propose their own alternative construction typologies, based on their experiences and specializations. It was envisaged from the beginning that the revision plans, as well as the determination of the supervisory engineer and their assistants, was to be defined by Rendel, Palmer & Tritton (RPT). The deadline for completion of works was set at 1,000 days.

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Six important international firms participated in the tender, demonstrating the high level of competition: Michel Kalaf (Iraq – Italy), Tehnoexportstroj (Bulgaria), Mostogradnja (Yugoslavia), Philip Holzmann, KE Zubin (both West Germany), and Skanska Kettana (Sweden – Lebanon). Some companies presented their offers on the basis of the official project, while others offered their own alternative solutions. The engineers of RPT rated the Mostogradnja project (designed by an engineering group which consisted of Mijat Trojanović, Živojin Darijević and Milan Gojković) as the most convenient, suggesting to the General Directorate of Roads and Bridges of the Iraqi Ministry of Transport that they accept it. The auction took place in Baghdad during the month of July 1962, where the Yugoslav company's project was confirmed. According to the October 1963 Mostogradnja company bulletin, "our version (of prestressed concrete) was evaluated as the most appropriate solution, both in terms of technical concepts and in terms of building construction".

The official agreement was signed on 21 January 1964, and Iraqi President Abdel Salem Mohammed Aref opened the building site on 11 April 1964. The load tests were performed between 15 and 22 April, 1967, after which the bridge was opened to traffic.

The engineering trio of Trojanović-Darijević-Gojković proposed a bridge with a prestressed concrete cantilever system (instead of a steel riveted structure), with a series of seven spans instead of the six proposed by the tender: the spans over the river were to be 51.4 m (lateral) – 5 × 70.8 m (central) – 51.4 m (lateral), with a total length of 511 m.

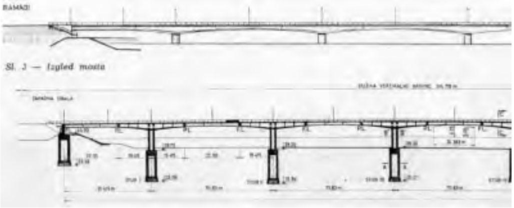

Figure 2. The Bridge over the Euphrates in Fallujah. Detail of the façade and longitudinal section. Source: Trojanović, p.132.

This was Mostogradnja's first experience abroad and the first construction in such unfavorable climatic conditions – the strong winds and very high temperatures typical of the region led to special cautions being taken on construction sites and in the construction of surveillance buildings, offices, canteens, workshops, employee apartments, and other ancillary and service structures. The skilled Iraqi workforce was a small one, and apart from some local mechanics, carpenters, and armorers employed on the construction site, most of the skilled workers belonged to the staff of Mostogradnja.

The river pillars were made of reinforced concrete, their unburied part narrowed for aesthetic reasons to measure 3.6 m in width (1/20 of the span of the road structure). Cantilever girders (box-section) were monolithically connected to the pillars, on which were placed prefabricated girders (in the center of each span and at the ends of the side spans). The spans of the cantilever portion of the road structure were 19.4 m from the axis of the pillar, while the dimension of the inserted suspended beams was – in all spans – 32 m.

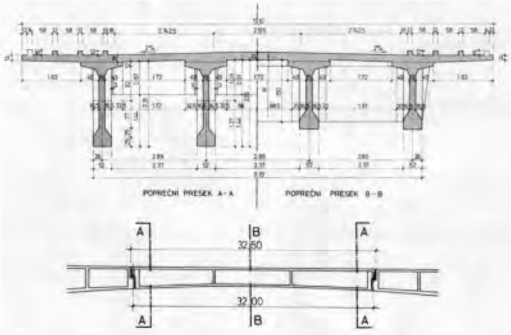

Figure 3. Cross and longitudinal sections of the girders. Source: Trojanović, p.134.

The project managed to reduce construction costs, thanks to a series of modifications made to the tender study proposal. (1) The designers succeeded in thinning the girders by 95 cm (from the corresponding steel construction in the official competition proposal) and as such (with the same free navigable profile in the river), it was possible to lower the level of the bridge deck by the same 95 cm. Thus, the ramp on the banks was shortened by a little more than 30 m, or, rather, the length of the more expensive high part of the reinforced concrete structure in the continuation of the viaduct was shortened. (2) The number of replicated elements increased considerably, allowing work on the bridge to become partially prefabricated; this, in combination with a rather rudimentary construction technology, made the undertaking of the project relatively inexpensive. (3) The project was then significantly adapted to local circumstances, economy, and interests. Instead of a steel construction, concrete was chosen – while Iraq lacked a metallurgical industry, meaning all metal products had to be imported, several cement factories existed and, according to the engineers, the quality of Iraqi standard Portland cement is excellent. This was important given the country's sulfate terrain. In addition, as was believed in those years, a project with prestressed technology was supposed to ensure durability at much lower maintenance costs than a steel bridge required.

While the decision to thin and narrow the single structural elements of the bridge was undeniably grounded in economic and technical reasons, at the same time, this action represented the moment in which the key decisions for the final aesthetic definition of the bridge were applied. The modeling of these thinned parts became an expressive and tectonic theme, the aim of which was to give the bridge as much visual lightness and elegance as possible. In order to achieve this final result, for the engineers

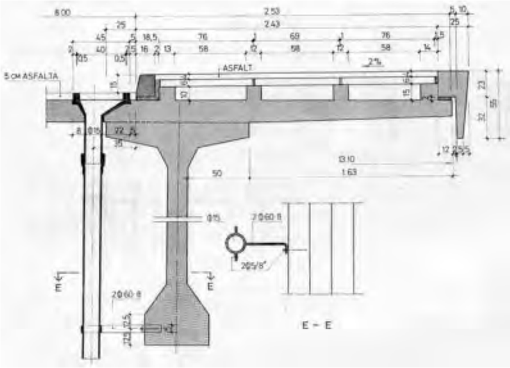

Figure 4. The pedestrian crossing over the bridge. Girder section, Detail. Source: Trojanović, p.134.

it was especially important – in addition to the mentioned narrowing of the river pillars – to design the profiles of cantilever elements and beams, which progressively thinned from the pillars to the center of the span, to a minimum thickness of 2 m (at about 70 m of the entire span). Furthermore, one additional detail contributed significantly to the visual thinning of the profile of the bridge when observed from the riverbanks: the sidewalks, or better yet, side pedestrian crossings, over the bridge, were placed on cantilever elements, which – as can be seen from the cross section – protrude from the box construction by slightly more than 2.5 m. This horizontal overhang casts a constant shadow across the internal structural vertical, one that thins the profile and visually increases the leap of the bridge. The designers thus demonstrated a very interesting sensibility in regard to the tectonic expression of the building artifact, a characteristic common among the great civil engineers of the time.

The final construction system of the Fallujah Bridge, as well as the detailed technical decisions that characterize the project, were based on the company's experience and on the availability of their construction equipment: especially with regard to complete pneumatic foundation equipment, as well as devices for, and experience with, hydraulic dredging of unbound material in the caisson chamber.

The cantilever elements of the main bridge structure were concreted on scaffolds. Beam formworks – made of wood and internally lined with hardboard panels were made of the available Yugoslav, Romanian, and Swedish hardboard (the last proved to be the best, as it could be successfully deployed up to three times).

Prefabricated girders (beams) were made on the upper side of the previously concreted and sufficiently hardened cantilever girders, having an individual weight of about 60 tons. The scaffolds, which had previously served the cantilevers, were reused for the installation of the girders: this double use of the same prefabricated grilles proved to be highly rational, and justified the adopted construction system and method of execution. Everything seemed to come together flawlessly, even with relatively modest equipment and mechanization.

The bridge was delivered a few months later than planned, primarily due to the longer duration of the excavation (harder layers than expected were found), and due to disagreements over the tightening force of the cables (problems with standards, which were resolved through discussions with the English company).

Figure 5. The Bridge over the Euphrates in Fallujah. The building site – scaffolds for the cantilevers. Source: photo collection of J. Jovanović.

During the Six-Day War (June 5–10, 1967), three Israeli planes set out to bomb the Fallujah airport and the newly built bridge. One of the planes was shot down and the operation halted: the surviving pilot, captured in Iraq, recounted the details of the mission and the reasons for the bridge being spared. Even after all the recent wars and conflicts in the Middle East, the bridge still serves traffic across the Euphrates.

3 MOSTOGRADNJA

Among the large construction companies that characterized Yugoslav modernization after World War II, Belgrade's Mostogradnja plays a central role. Unlike the more renowned Energoprojekt, Mostogradnja was primarily an engineering company, highly qualified and economically competitive, specialized in the construction of bridges with large spans and various other construction typologies. Its post-war development represents an interesting example through which one can read and historicize the development and role of construction companies in Socialist Yugoslavia, the way they were organized, and the reasons behind their international success.

Mostogradnja was formed on February 5, 1945, shortly before the end of the Second World War, in the immediate wake of the liberation of Belgrade. The company was created with the task of rebuilding destroyed bridges across the devastated country: the first reconstruction in which the company was involved was the railway bridge over the Tamiš River near Pančevo, followed by reconstructions of a series of bridges over the Danube (near Bogojevo), Tisa (near Titel), etc..

Very soon (from 1947 onwards), it began to receive orders for the construction of new bridges (not only renovations and reconstructions) and, while in its initial phase the company specialized in railway bridges, it gradually expanded its competences and developed specializations for all types and systems. During the 1950s, the company expanded its activities to other civil engineering typologies, including hydraulic structures, railways and warehouses.

In 1959, it reached new dimensions and significant technical and operational capacities, merging with another large company (Pionir) that worked in the same field. While Mostogradnja had primarily been a contractor since its foundation, at the beginning of the 1960s it also assumed a role in the design and contracting of bridges. With the arrival of engineers Ilija Stojadinović and Dimitrije Ćertić in 1963, the formation of its Project Bureau, which dealt with the design of investment facilities, as well as technological procedures, began. In this context, the project and construction of a prestressed concrete bridge over the Euphrates (Fallujah, 1964–1967) represents a key moment in the history of the company. As its development until the end of socialist Yugoslavia showed, Mostogradnja affirmed itself as a constructor of prestressed bridges at the international level, being among the highest achievers in this field on a global scale.

However, the bridge in Fallujah was not designed within the company, but in cooperation with the Institute of Civil Engineering from the Faculty of Civil Engineering at the University of Belgrade, another very important public institution in Yugoslavia for the development of concrete structures, from both a theoretical and practical point of view. The main authors of the bridge were professors Mijat Trojanović, Živojin Darijević and Milan Gojović. The key figure of this trio is Mijat Trojanović, who taught the courses *Concrete Bridges*, *Concrete Technology*, and *Concrete Dams*, and from the first post-war years was the head of the Department of Materials and Structures at the University. Trojanović was a construction expert who was educated in the Kingdom of Yugoslavia and was the author of one of the most important bridges built between the two wars (completed in 1940); the imposing bridge on Tara in Montenegro, perfectly integrated into the surrounding landscape of the canyon, made of reinforced concrete arches that were connected to the bridge deck by thin pillars, as in the Maillart system. Trojanović, who graduated from the Civil Engineering Department of the Belgrade Technical Faculty in 1925, specialized abroad, first at the Technische Hochschule in Vienna and then at the École nationale des ponts et chaussées in Paris. From 1926 to 1928, he worked as a construction engineer at Grands Travaux de Marseilles in Paris, a leading company in French reconstruction works after the First World War. This significant international experience is evident in the engineer's bibliography, as he published a series of high-quality textbooks and monographs on the topic of construction using reinforced concrete and prestressed systems during his professorship in socialist Yugoslavia.

In this context, it should be noted that Mostogradnja – both in cooperation with external experts and within its Project Bureau – built a series of very important bridges in Yugoslavia during the 1960s and 1970s. The engineers of Mostogradnja achieved excellent results in the realization of complex structures using different technologies and construction figures. In particular, its expertise and fame increased with the construction of the bridges over the Danube (Novi Sad – mixed technology: prestressed concrete + steel structure; Smederevo – steel), over the Sava (the famous Gazela Bridge in Belgrade – prestressed + steel; a second one, a suspension bridge), across the Mala River in Montenegro (reticular system), Pag bridge (arch bridge), and Tito's Bridge, which connects Krk Island to the mainland (a concrete arch system with the largest span in the world until the end of the 1980s).

In the context of its success on the domestic and international markets, and thanks to the trust gained with the Euphrates Bridge, Mostogradnja was awarded additional projects in Iraq in 1974: for two bridges over the large Hila and Garaf canals (chief engineer Vukan Njagulj). A year later, Mostogradnja won the competition for the construction of a bridge over the Tigris River near Numaniyah in Iraq, over 600 m long, where one span of the bridge was opened by rotating upwards in order to allow passage of ships with high cargo. At the beginning of 1979, Mostogradnja won another international competition, for the construction of over 40 facilities on the first section of Highway No. 1 in Iraq, in the Baghdad zone, from Abu Ghraib to Hillah (the section of the Baghdad – Hillah highway is 106 km, on which 56 road bridges have been built. The total length of all bridges is 3,406 m). Basically, all these bridges have a similar construction typology, composed of pillars and prestressed beams, mostly of the prefabricated type. Unlike the bridge in Fallujah, the beams/girders rest directly on the pillars, and not on the cantilever elements.

Also interesting is the use of prestressed concrete, a technology that was developed during the 1950s and dominated Yugoslav construction until the 1990s, especially in the field of building bridges and large span structures (sports halls, factories, crane tracks). The turn towards prestressed concrete happened for very pragmatic reasons: a lack of iron, i.e. high-value steel for the needs of construction, which was imported from abroad until the construction and consolidation of Yugoslav ironworks, and the existence of quality raw materials for concrete production. Furthermore, owing to the application of prestressing, the consumption of concrete in structures is reduced by up to 30% in relation to reinforced concrete. When it entered foreign markets, which began in 1952, Yugoslavia did not hide the fact that its main motives were economic profit and increased employment in the construction sector, for which there was often not enough work continuously available within the country. However, when assessing which structural systems would be the most favorable and rational for construction, Yugoslav builders often referred to experiences from their own country, and the reconstruction and construction that took place after WWII. Technological transfer was often by means of international technical assistance or bilateral agreements, but there was also an awareness of the situation of post-colonial countries, which was similar to the legacy of liberation from imperialism that socialist Yugoslavia was founded upon (as it was considered). Therefore, in addition to technology, the Yugoslav authorities offered other types of assistance and a kind of mentoring role, based on their own experience of development of self-management, as well as through solidarity actions and favorable loans.

4 IRAQI-YUGOSLAV RELATIONS

The quality of both the project and the realization of the bridge are indisputable. However, it is clear that the penetration of Mostogradnja into the Iraqi market and its success across more than three decades is the result of the particularly open and positive diplomatic climate created between the Socialist Federal Republic of Yugoslavia and the newly formed Republic of Iraq in the 1960s.

On July 14, 1958, General Qasim led a coup in Iraq, which abolished the monarchy and proclaimed the Republic. The new government annulled all agreements with Great Britain and most of Iraq's international allegiances that were formed under the protectorate and influence of British colonial domination: it implemented Iraq's withdrawal from the Baghdad Pact and the breakup of the Federation with Jordan. In this sense, the spirit of "Nasserism", which combines elements of Arab socialism, republicanism and nationalist anti-imperialist aspirations with the aim of creating pan-Arab solidarity, slowly spread to Iraq and the Middle East in the 1950s, thus seriously threatening Western interests in the area. Tito, as one of the greatest international allies of Nasser's United Arab Republic (UAR – Egypt and Syria) reacted quickly to the new situation in Iraq through Yugoslav diplomacy, openly demonstrating support by inaugurating the embassy in Baghdad in 1958.

According to diplomatic correspondence, exchanges of opinions and agreements on global and Middle Eastern crises were being formulated, and mutual economic negotiations discussed. This led to the inclusion of Iraq in the Non-Aligned Movement: Baghdad participated as one of the 25 founding states of the movement at the first summit in Belgrade in 1961.

Mutual diplomacy was actively engaged in from the very founding of the Republic of Iraq. Economic relations with Yugoslavia were regulated by the Agreement on Trade and Economic Cooperation, which was signed at the end of 1958 and which provided for payment in convertible currency. Since the very establishment of relations, Yugoslav exports to Iraq hovered at around a million British pounds each year, while imports were at around 10–15% of exports annually. However, an equal balance was practically impossible to achieve due to the low diversity of Iraq's supply (Yugoslavia's imports from Iraq virtually exclusively consisted of dates).

Edvard Kardelj, one of the main ideologues of "self-government", and one of Tito's closest associates, was in Iraq on a diplomatic visit in December 1962 when he offered a series of economic aid packages, and proposed various services to the local government: the construction of a Zastava factory (Yugoslavia's main automobile manufacturer), the assembly of Iraqi merchant ships in Adriatic shipyards (thus trying to compensate for Japan's dominance in that economic branch); among various other actions. Kardelj, as an envoy of the Yugoslav government, stimulated the opening of the Iraqi embassy in Belgrade, as its main representative office for Eastern Europe.

Only a few of these policies were realized. The intensity of mutual political and economic relations fluctuated depending on the state of Iraq's internal situation and its relations with other Arab countries, especially the UAR. Certainly, for Yugoslavia, from the very first years onward, the economic relationship with Iraq was not satisfactory, but it was assessed that it could offer a rather broad perspective. In particular, the freedom of the Iraqi market and its openness to a number of foreign partners put the Yugoslav side in a rather unfavorable position, as competition from other countries was very strong. However, among the different economic branches, there were opportunities to engage various Yugoslav construction companies, which from the beginning proved to be highly competitive. It is interesting to note that there was a proposal to compensate Mostogradnja for the construction with oil. However, the services of the Iraq Petroleum Company could not be included in the mutual exchange, because the oil was – even after the coup – not under the control of the Iraqi government, but rather the British. According to available documentation, socialist Yugoslavia operated on the international market according to the clearing system, especially with the countries of the Non-Aligned Movement and the Warsaw Pact, as they often lacked exchangeable currency. There are records of crude oil being used as a bartering tool only during the 1980s, when there was a crisis in the monetary compensation for the realized work.

Mostogradnja's bridge on the Euphrates, whose investment value was around $4.5 million, was not the only commission Yugoslav building companies had in Iraq in those years. Several companies were hired to build transmission lines, dig wells, pave asphalt surfaces, and so on. After the Fallujah Bridge was completed, the Institute of Civil Engineering team designed four more bridges in Iraq: the Rabar Koi, Dialah, and Hadita Bridges across the Euphrates and the Tikrit Bridge over the Tigris, later also working on projects and budgets for military bases "404" and "606", on the Kol 1 warehouses, and on the Al Shamal thermal power plant. It is known that, through Yugoimport SDPR, Yugoslav companies worked on the construction of military bases and airports in Iraq. Iraq was a significant market for Yugoslav construction, as evidenced by the fact that, during the 1960s, the Yugoslav Construction Center, commissioned by the Federal Chamber of Commerce, processed the market and translated legal regulations and conditions for domestic construction companies.

Mostogradnja, in the process of bankruptcy today, is practically inaccessible to researchers, with its employees protesting on the streets because of unpaid salaries. In Iraq, most of the buildings the company constructed were damaged during the wars of the late 20th and early 21st centuries. The development and ultimate downfall of such a big state company and its international fortune is, until-recently, not only a rather unknown example, but also a crucial and symbolic story through which to read historic epochs and their transformation parallel to changing geopolitical balances.

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History of Construction Cultures – Mascarenhas-Mateus & Paula Pires (eds)

Non-alignment and patterns of freedom and dominance

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ABSTRACT: This paper deals with two main themes in the transnationalism of the history of construction in Egypt: (a) Freedom patterns through eagerness to modernize; (b) Aspirations to dominate the newly independent Third World. These two themes evolved around 1964, a tipping point in construction history in Egypt, that is marked by hosting both the second NAM (Non-Alignment Movement) summit and the first Arab League. Before 1964, projects such as the Cairo International Stadium (1956–60), Aswan High Dam (1960–70), and the Hilton Hotels in Egypt (1957–65), manifest eagerness to modernize, and liberation from Third Worldism's judgements. This eagerness led to Nasser's pacts with the superpowers despite being a NAM advocate. The dominance aspirations, on the other hand, are manifested in the expansion of Egyptian involvement through construction projects in the newly independent Arab and African countries. Both themes highlight the discursive ties that were established through the transnational history of construction.

1 NON-ALIGNMENT AND REFLEXIVITY

"We are the two greatest continents on earth. We have the greatest pool of manpower, the greatest pool of all, materials. … with our collective will, no strategic war will take place–if we do not participate in any sense" (Jansen 1966, 19).

This statement by the Syrian delegate at the Bandung Conference (1954), encapsulates the emerging Third World's confidence and self-awareness. The Bandung conference, apart from its political results, epitomized the birth of the Third World (Korany 2018). This notion of Bandung's Third Worldism was rearticulated by the Non-Alignment Movement (NAM), which was focused on the non-alignment of postcolonial countries with the superpower blocs. The most preeminent advocates of the Movement were Egypt's Nasser, India's Nehru, and Yugoslavia's Tito. Focusing on the Egyptian case, 1964 represents a tipping point in this context.

In 1964, two major summits took place in the country: the NAM in Cairo, and the Arab League in Alexandria. This paper asks two questions in considering the essence of the argument: Does the synchronicity of the two summits in September 1964 manifest Nasser's aspiration to orchestrate or dominate the Middle Eastern scene, and if so, how did this aspiration relate to transnational construction practice outside Egypt? How did foreign construction partner ships find their prospects within some projects in Egypt regardless of the NAM and Nasser's pan-Arab rhetoric?

With these questions in mind, this paper will deal with two main themes in the transnationalism of the history of construction in Egypt: (a) Freedom patterns through eagerness to modernize; (b) Aspirations to dominate the recently independent countries through knowledge prudence. The occurrence of these two themes around 1964, this paper argues, introduces the notion of reflexivity, crystalized by Ulrich Beck, Anthony Giddens, and Scott Lash in *Reflexive Modernization* (1994).

This paper argues that eagerness to modernize resulted in sustaining "the same" Third Worldism and dominance attitudes of colonization (Beck et al. 1994, 6). Therefore, the two themes highlighted in this paper are governed by reflexive dynamism, which is grounded in a "cognitive and social construct" of the regime's self "confrontation" with its own "bases and limits" (Beck et al. 1994, 6). In this way, this paper highlights that Egypt's postcolonialism, and its associated socio-political transnational transformation, is shaped by reflexive modernization, which involved both patterns of freedom from self-judging Third Worldism and affairs of dominance within the recently dependent countries.

Here, Nasser's advocacy of the NAM, marked by hosting the second summit in Cairo 1964, was motivated by his desire to gain both freedom from Europe and dominance within the region. These two facets within Nasser's agenda consequently led to the alteration of Egyptian foreign policy to ostensibly suit non-alignment principles. The freedom patterns, on the one hand, were associated with eagerness to modernization, which consequently led to precarious pacts with the Soviet bloc (Peretz 1965). On the other hand, the desire to dominate led to Egypt's ostensibly neutral construction endeavor within the Third World. Observing the transformative nature of construction transnationalism, one may claim that the 1964 Cairo NAM Summit represents a turning point

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between these two facets in the transnational history of construction.

2 FREEDOM PATTERNS

At the close of the royal regime, and the launch of Nasser's rule before 1964, Egypt began to witness the rise of many projects announcing a new progressive era. The paper here focuses on three construction projects that manifest the reflexive modernization and freedom aspiration of the sixties. These projects are the Cairo International Stadium (1956–60), Aswan High Dam (built 1960–70), and Hilton Hotels (1957 and 1965).

The story of Cairo International Stadium goes back to the thirties when the National Olympic Committee invited the famed German architect Werner March to design it. However, the war prevented him from developing any plans. In 1953, despite the Arab nationalist tendency, March was re-invited to develop plans for the stadium along with its surrounding city quarter, accommodating about 60,000 inhabitants. The whole project was supposed to finish before the 1968 Olympic Games which were planned to be held in Egypt. The stadium was the first of its kind to be made to Olympic standards in the Middle East and Africa.

The project occupied an area between downtown Cairo and the north-eastern suburb of Heliopolis. This location was March's choice due to its relative proximity to downtown Cairo and Heliopolis. The location was also surrounded by advantageous infrastructure, consisting of several important traffic arteries, a metro line, and a train line. Around the same time, the area next to the future stadium site had been chosen as the site for a new city extension, which was to be called Madinat Nasr, or Nasr City.

The cost of the buildings and the site was calculated to be 2,550,000 Egyptian Pounds. The time allowed between the signing of the contract and the start of construction was between 44 and 56 weeks (Seidel 2019), which was extraordinarily short, by the standards of that era. Some of March's Egyptian partners, contributors, and counterparts were engaged in the design and implementation phase, such as Salah Ghaleb, Dr Ahmed Moharram, Dr Michel Bakhoum, Galal Hussein Kamel, Dr Mohamed Sayed Youssef, Mustafa Showki, and Thabet Barsoum (Seidel 2019). Other European involvement was through Reynaers – a leading European specialist in innovative and sustainable architectural aluminum solutions – who supplied the curtain-walling system for the stadium.

Most important was the choice of the technical and construction office which was the responsibility of the Egyptian Government. It awarded the contract to the Egyptian firm of ACE Moharram Bakhoum. The firm was an association between Bakhoum (PhD, Illinoi, US 1948) and Muharram (PhD, London, UK 1949), both were faculty members in the Civil Engineering Department in Cairo University. The firm was established in 1950, and was then known as "Consulting Engineers, Dr A. Moharram and Dr M. Bakhoum". Bakhoum's knowledge of concrete, coupled with Moharram's comparable proficiency in steel, made them ideal collaborators. The firm took part in several seminal projects in Egypt, for example, Cairo's International Fair Ground, and the tunnel under the Suez Canal, connecting mainland Egypt to the Sinai (El Rashidi 2014).

ACE's first regional activity took place in 1961 with the structural design of the first production line of the Yamama Cement Factory in Riyadh, Saudi Arabia. The project was completed through partnership with the German multinational conglomerate ThyssenKrupp AG, whose responsibility was the industrial design and steel production (ACE Moharram Bakhoum website). Soon after, in 1965, ACE was awarded another regional contract comprising the redesign and construction supervision of the runways and taxiways of the Kuwait International Airport. Most important, the ACE firm was one of the major participants in the construction of Aswan High Dam, along with the Arab Contractors (back then: Osman Ahmed Osman Contracting) and the Moscow-based Hydroproject Institute (Smith 2012, 694).

The Dam's main objectives were to control the water resources of the Nile, to expand cultivation, and to produce cheap hydro-electric power for industrialization and development. Therefore, it can be considered another project that heralded the modernization and freedom aspirations of the era. An agreement with the Soviet Union was reached in 1958 for a loan of about $100 million to meet the foreign exchange requirements of the first stage, that was, the construction of the cofferdams, the diversion canal, and the six tunnels. The second stage, started in 1960, included construction of the project to its final stage, together with the power station and transmission networks to Cairo.

Involvement of the Soviet bloc was a response to the cancelled funding loans by the United States of America and Europe in 1956. This date also brings forth the construction of the Cairo Tower. The construction of this 187-meter concrete and iron lattice tower was considered a symbolic dismissal of America's involvement in the Egyptian context, and an initial invitation to the Soviet's (Wawro 2010). However, Soviet involvement in the dam caused a significant exchange of knowledge, as many Egyptian skilled workers and engineers were later recruited by their Soviet supervisors in Russia (Mossallam 2014). The intricacies of Soviet involvement in the High Dam, the world's largest embankment, as an industrious and defensive national project, was indispensable for Nasser's industrialization, but manifests a discursive continuation of colonial reliance.

This tendency of continuing colonial dependency within freedom reflexivity is also manifested in the continuation of the expansion of Hilton Hotels during the height of Nasserism. The design and construction of Nile Hilton (1957), Aswan Hilton (1963), Luxor Hilton (1964), and Alexandria Hilton (1965), were cooperatively done with both the American modern

Figure 1. Luxor Hilton 1963, watercolor rendering courtesy of Ritchie Architects & RiadArchitecture.

architect Welton Becket and the Egyptian architect Mahmud Riad working together. While Becket provided the preliminary schematic design, Riad, through his office RiadArchitecture, worked on the design development. As a local consultant, Riad reworked many of Becket's impractical ideas, such as constructing a bridge from the hotel over to the Nile (RiadArchitecture website). Riad, also incorporated the design of the Nile Hotel with the design and construction of the Arab League Headquarters (1955), to facilitate the accessibility of foreign personages between the League and the Hotel. Welton Becket's associates were responsible for the interiors as well as the mechanical and electrical engineering of the project. It is worth mentioning here that Riad's office was later contracted to design the extension of the Nile Hilton in 1964.

With the success of the Nile Hilton, the Hilton Hotel Company (in partnership with the Egyptian Touristic Company) brought their consultant architect, J.A. Ritchie (based in Italy), and sought the consultancy services of RiadArchitecture. They commissioned the office to work on the design development of other hotels: the Alexandria Hilton, Luxor Hilton, and Aswan Hilton. The Alexandria Hilton, extending views towards the Mediterranean, was the simplest in form. The Luxor Hilton (Figure 1), most similar to the Nile Hilton, presented an elusive Ancient Egyptian burst in designing the hotel podium.

In this way, foreign partnerships continued throughout the construction and architectural professions, regardless of NAM and Nasserism rhetoric, in the projects commenced before the 1964 Cairo summit. This denotes reflexivity of freedom which resulted from the unconscious adoption of the antecedent perspectives of the colonizer while regaining power.

3 DOMINATION ASPIRATION

The colonial past also caused an eagerness to dominate that, this paper argues, found its opportunity in newly independent Arab, Gulf, and African countries. Egypt used to play a significant role in supporting independence movements in the Arab countries, because Nasser aspired to maintain political legitimacy and regional leadership. This leadership was also evident in professional and technical exchanges. Transcultural construction projects within the newly independent countries were realized through the practice of private engineering officers and contractors who either suffered from Nasser's enactment of egalitarian policy and nationalization of businesses, or who achieved regional skill recognition. In the late sixties, Egypt played a formative role in the development of the urban fabric of the cities of the Arab World, through the Muhandiskhana, the first engineering school in the Arab world, established in the nineteenth century by Muhammad Ali.

Engineering schools in Kuwait, Tunisia, Libya, and the Arab countries in general, were inaugurated as late as the 1960s. Taking Kuwait, Libya, and Yemen as cases of newly independent countries, Egyptian architects and engineers played a significant role from the 1950s through to the 1990s. Although this role may seem peripheral compared to these countries' long history of modernization, Egypt's importance here stems from highlighting Third World independency as an opposing story to the comprehensive reliance on the First World. For Kuwait, one of the famed practicing architects was Dr Sayed Karim. One of the first multi-storey concrete buildings of Kuwait, the Thunayan al-Ghanim building, was designed and built by Kareem, the Egyptian modernist, in 1954 (Fabbri 2020, 129). At the time, the building was considered one of the most advanced in Kuwait and one of the first to have an elevator.

Most important, in 1961, as Director General of the Cairo Municipality from 1954 to 1965, Mahmud Riad was invited to the United Nations Experts' meeting held in Stockholm. This transnational forum introduced him to the Kuwaiti Government, to which he was appointed a Technical Advisor for the Ministry of Public Works (1965–79) (El-Shahed 2013). Before this, he was invited to design the masterplan for the complex of the Kuwait Sports Center in Kifan in 1963 (RiadArchitecture website). After independence, Kuwait went through extraordinary social and civic transformation. However, Kuwait had not yet established its engineering education and architectural professions.

Therefore, envisaging the Old City center, which was completely demolished, attracted major international designers. In 1965, Riad was invited along with fellow Egyptian Architect Omar Azzam and Dutch Jacques P. Thijsse, Professor of Comprehensive Planning at the Institute of Social Studies in The Hague, to provide consultancy on the development plan for the city (Figure 2). In fact, Riad's relationship with the Kuwaitis started first as an Arab confidant who could be trusted to mediate between the Kuwaitis and the Western influx of architects and professionals. Riad's role in the technical department can be understood best as somewhere between a client representative, commissioner, or curator of the city. Rather than executing and designing projects himself, he wrote the briefs, managed, and supervised the architects' work, as well as negotiated the terms according to which the projects were executed.

Riad's role can be identified in the letters exchanged between figures such as Kenzo Tange, Reima & Raili Pietila and VBB & Sune Lindstrom who discussed with him specific amendments and suggestions he had made to their own designs. It can also be identified in other correspondence pitching their services (RiadArchitecture website). Amongst the important buildings to be designed and constructed by foreign firms was the Kuwait Water Towers in 1965, known as "the mushroom towers". These reinforced concrete towers were constructed by the Swedish engineering firm VBB (since 1997 Sweco) in collaboration with the engineer Mustapha Rifai (Wikiarquitectura). The company built the original five groups of water towers, 31 in total, each tower holding 3000 cubic meters of water, designed by architects Sune Lindströ and Malene Björn (Holod & Rastorfer 1983).

Similarly, Libya's technical inability to cope with its post-independence modernization aspiration attracted foreign and Egyptian contracting and engineering firms. The Egyptian involvement was not only valuable to Libya, but also helped Egypt to overcome the recession in the construction field that occurred during the construction of the dam and the 1967 crisis. Large construction companies benefited from the growing wealth of oil revenues in countries such as Libya. Therefore, many Egyptian firms earned contracts in public housing and in infrastructure. One of the most successful Egyptian companies in Libya was Osman Ahmed Osman, which was a major participant in Aswan High Dam project. There have been many "joint" Egyptian-Libyan projects. The most important one was a joint water project through which Libya would obtain water from the Nile, in exchange for funding the extension of the Nubariyah Canal (Intelligence Memorandum 1972).

Another significant project was the Hydro-Agricultural Development Project (Great Man-Made River) in 1969. It was assigned to the Egyptian firm ECG (Engineering Consultants Group). The project was launched as a business partnership by Mr Mahmoud Sami Abdelkawi and Mr Ashraf Hassan Allouba. This highly standardized water-supply project included drawing underground water from the aquifer Sarir well field, brought together through an 800km long collection and then pumped 350km to the coast (Kuwairi 2006). For a further 500km, water was then transported along the coastal area of the bay, where it was stored and distributed (ECG website).

In Yemen, the Egyptians' presence was instrumental in developing the country's infrastructure. In fact, between 1962 and 1967, Egyptian experts supervised the physical and organizational building of the country. This migration contributed to the development and construction of the country. Moreover, many authors argued that the Egyptian migration started to have a socio-political impact. This impact was due to Nasser's advocacy of Egyptians' participation in political activism that supported his regional ambitions in Libya, Syria, Yemen, and the Persian Gulf – according to state foreign policy priorities between 1952 and 1967 (Tsourapas 2016, 338).

INSTITUTE OF SOCIAL STUDIES

KU/2078

10 May, 1965

Mr. Mahmoud Riad,
2, Sharia Jawad Husni,
C a i r o

Dear Mr. Riad,

Both you and I have been invited to come to Kuwait for the evaluation of the Skeleton Land Use Master Plan.

The Planning Board suggested that we should be there simultaneously so that we would be able to study and discuss the Plan together. This is a sound idea; the only difficulty is to make the arrangement that we both are free at exactly the same time during the period between the middle of July and the end of August. Climatologically this is not very attractive, but I hope we can take the hardship.

The Board requests us for several days, which for me would mean 5 days (journey included). As I have also other assignments I could not arrive earlier in Kuwait than August 5. As August 6 is a Freiday, it might be difficult to start the activities earlier than August 7 (for me August 6 would be O.K.). I will be available until August 19.

I hope that you will be able to make suitable arrangements in order to be available for some days during the same period.

It is appealing to me to have another chance to cooperate with you and so I am looking forward very much to be meeting you soon again.

With kind regards,

Very sincerely yours,

Prof. Jac.P. Thijsse

Figure 2. Letter to Mahmoud Riad from Jac. P. Thijsse regarding the evaluation of the Kuwait Skeletal Masterplan.

In Yemen, the civil construction sector was the responsibility of the Ministry of Public Works, before the 1962 revolution and during Yemen's civil war that extended into the seventies. The country before 1962 had one paved road only, which connected Sanaa with Hodeidah City. The country also suffered from a lack of infrastructure and public services, it had no schools and no hospitals. The new government was challenged with a massive developmental task (Miles 1984).

Within six months of the Imam's overthrow, Egypt helped to found ministries of Foreign Affairs, Education, Health, Tribal Affairs, Interior, Justice, Agriculture, Finance, Economy, Labour, and Information and administrative bodies, such as the Yemeni central bank (established in 1971; Figure 3). To accommodate such entities, which adopted Egyptian blueprints, hierarchies, and procedures, Egyptian engineers built whole streets of modern block buildings (Schmidt 1968, 81). Modern construction in Yemen refers to buildings that were constructed after the 1960s, where new materials were used. The two decades of the 1960s and 1970s witnessed the appearance of new materials such as hollow cement blocks for walls, reinforced concrete slabs replacing traditional roofing and flooring materials, reinforcing rods and structural steel, and terrazzo and cement floor tiles (Miles 1984). Cement block walls were usually plastered in the interior and exterior (Sultan & Kajeski 2003).

While Nasser dreamed of mirroring the United Arab Republic in Yemen, the modernity offered by the

Figure 3. Yemen Central Bank, Courtesy of courtesy of Aga Khan Documentation Center, MIT Libraries (courtesy of architect, AKDC@MIT).

Egyptian engineers was discernably Egyptian (Orkaby 2014, 11). Therefore, Egyptian involvement had significantly influenced not only state institutions but perceptions of the state and expectations of what it should be (Wedeen 2008, 179). In this way, the joint Egyptian-Yemeni public enterprises, dominated by their Egyptian parent companies echoed Egyptian nationalization policies (Stookey 1978, 237). Yemen was also open to other socialist countries such as the Soviet Union and China, which aimed to secure their positions within the region.

These rival forces provoked Nasser's competitiveness, whose desire to dominate was manifested in an architectural contribution within Africa: The Amitie Hotel in Bamako, Mali (Figure 4). Despite the 1967 Israeli crisis-infused economic and construction predicament, Nasser's persistence with diplomatic ties and proclaiming leadership was irresistible. In line with previous Arab countries, after independence in the 1960s, Mali was seeking rapid development. The Amitie/Friendship Hotel was one of Egypt's technopolitical initiatives in Africa. Adopting an international style, the design of the building was by the architect M. Ramzy Omar who was assigned to undertake the project by the Ministry of Foreign Affairs. The required building materials were transported from Egypt to Mali. Moreover, Egyptian engineers and contractors were commissioned to work in Mali for constructing tens of kilometers of road infrastructure. This exchange of Egyptian technical expertise was a fundamental element in the postcolonial future of the nation.

Figure 4. Amitie Hotel in Bamako (courtesy of Fred van der Kraaij, Wikimedia Commons).

4 CONCLUSION

The participants of the Non-Alignment Movement, from the start of the Cold War, endeavored to sustain constancy by establishing multifaceted ties, throughout the years. However, in the Egyptian context, new horizons arose out of the strongholds of Nasserism. During the rise of Nasser, the recently independent self was under pressure of Third World judgement. Therefore, hasty development projects took place that resulted in discursive ties and partnerships of freedom and dominance.

The partnerships of freedom were manifest in continuing construction partnerships with the superpowers. Despite being a NAM advocate in the Arab region, to achieve modernism and realize the dream of freedom after independence, Nasser continued partnering with the USA in the design and construction of projects such as the Hilton Hotels. He also maintained ties with the Soviet bloc, as one of the world's superpowers, to achieve his national Aswan Dam dream. In this way, this paper highlights the continuation of the foreign partnership, regardless of NAM and Nasser rhetoric, in the construction of projects started before the 1964 Cairo summit. This denotes reflexivity of freedom which resulted from the colonial antecedent. After the 1964 NAM and Arab League summits, Nasser's dominance aspirations led him to strive for leadership throughout the newly independent countries. This was reflected in the various construction projects undertaken through Egyptian private and public commissions and partnerships within the global south.

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History of Construction Cultures – Mascarenhas-Mateus & Paula Pires (eds)

Indian immigration and building construction in the UAE: Beginnings of a pilot study

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ABSTRACT: Often relegated to the background, the global pandemic has directed attention to some of the potential pitfalls of geographically and culturally distant professional relationships in the design and realization of ambitious architectural work. Within the specific context of the UAE, this global interdependence also extends to the manual and technical labor. The current paper, which is part of a pilot study, begins to explore through oral histories, the transnational networks of both manual and professional labor across the AEC disciplines between the UAE and the Indian subcontinent which began with the oil boom. As we will see, regardless of the origins and/or intentions of design, the ground reality of execution—vis-à-vis materials supply and construction—was predominantly dictated by expatriate Indians (mostly Malayalees, as in the current paper)—in the form of shop keepers, store managers or engineers; thus, playing a conspicuously important, yet unrecorded, role in the realization of the architecture of this place.

1 INTRODUCTION

1.1 *A brief background sketch*

In September 2014, after joining the School of Design and Architecture at the Dubai (UAE) campus of the Manipal Academy of Higher Education (formerly “Manipal University”), I used to take the University bus to the campus, and back. A drive of about 25 minutes, the bus generally took 35–40 minutes to reach the University after picking up students and faculty near or on the same route. I became friendly with the driver, Imtiaz Khan, a Pathan from Peshawar, Pakistan, who was the assigned driver to the route on which my apartment was located. I enjoyed sitting next to him in the front of the bus to view the contradictions of this relatively young landscape coming to life from 6:15 am onwards, which used to be my pick-up time. We would often converse in Hindi/Urdu about Bollywood cinemas or his homeland, and he would quickly answer a friend’s call in his native language Pashto and return with ease to speak with me in Hindi/Urdu. In about two years, once I had saved up enough to buy a car, my bus rides with Imtiaz stopped.

The bus carrying me was filled with some 15–18 students including one or two faculty; the students were primarily first-generation children of Indian expatriates who were decidedly admitted to a comparatively affordable and reliable “Indian” university in the UAE. The view is a typical scene I would see in a neighboring bus when stopping at red-signals—the neighboring bus would also have predominantly Indian or South-Asian labor packed tightly in a bus that would be transporting them from a labor-camp to a site where Dubai might be breaking yet another Guinness World Record. As I would look at them, the half-asleep, curious, and bored faces would glance back and return to their slumber.

Figure 1. Sketch by author on his mobile device (Samsung Note 4), March 2015.

This 2015 drawing reflected a certain reality, and a certain condition of this place. Just a couple of years ago—in 2013—the Paris-based Bureau International des Expositions (BIE) consisting of 168 member nations, had awarded Dubai the bid to host Expo 2020. An extremely proud moment for this young nation—the first in the Middle East to be awarded such an opportunity—this was announced proudly on the Burj Khalifa in the New Year celebrations of 2014.

1.2 *Architecture and the act of building*

Architecture, beyond the stylistic and/or formal, or philosophical discussion it generates, is one of the most labour-intensive activities in which a multitude

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of players or agents are exploited to make building itself a profitable activity.

Since the discovery of oil in the early 20th century, the countries of what is now known as the Gulf Cooperation Council (GCC, founded in 1981) – comprising of Qatar, Kuwait, Bahrain, Oman, the UAE and Saudi Arabia – have experienced unprecedented exponential growth. The global increase in the prices of oil and natural gas in the 1990s furthered the economic growth of these Gulf countries. However, as observed by Elsheshtawy, such a growth has also created a certain economic disparity amongst the Arab countries—creating an increased migration of people from poor Arab countries to the richer ones in the GCC (Elsheshtawy, 2013). Mega events such as the (now-rescheduled) Dubai Expo 2020, and the 2022 FIFA World Cup in Qatar are signature projects that exhibit the spending powers of these young nations in creating spectacular architecture.

However, beyond the critiques of style (or lack thereof), or theoretical or formal, and still grounded in the top-to-bottom analyses of, say, “quirky” Dubai architecture, one must really look very closely into the very *acts* of building. The acts of building such megaprojects, that start identifying with the place itself—while originating from an ambitious political will, and ideated and drawn in an architect’s office, is brought to reality by those who are at the site—and those who deal with the materials that go into building. In the case of the GCC, the realization of such large scale and mega projects depends considerably on the south Asian migrant labor force. It is then no surprise that the Middle East is the largest recipient of labor migrants in the world (Thiollet 2016).

1.3 *The Indian expatriate*

A study in 2005 found an 89% foreign born population in Dubai, of which 51% were Indians (Elsheshtawy, 2013). The often-deplorable situation and conditions of such transient workers (now defined as “temporary workers”) has been the subject of several research reports, and media attention too. While the plight of the workers is noted, and reforms are now in place to check the migrant populations and/or their conditions, the recent pandemic episode has highlighted not only the pitfalls of recruiting such transnationally dependent workforce but has also generated discussions regarding the safety and security of these rich countries.

While it can be argued that the transnational and transient labor force is a machinery of exploitation designed to benefit one party at the cost of the other, the GCC is also replete with stories of extreme successes—specifically within the Indian expatriate community. In the context of the Gulf region, including the UAE, names such as those mentioned on the constructionweekonline website are synonymous with rags to riches stories of Indians who have made this place their home since the 1930s (Week 2019). The stories of that period of the first generation of Indian expatriates who started bringing some radical changes to the socio-cultural landscape of this region (such as the introduction of electricity in 1957 by the legendary Indian expatriate, Maghanmal Pancholia) are truly exceptional and inspirational.

1.4 *A brief history of oil in Dubai*

Oil was discovered in 1966 in Dubai and within a decade, the erstwhile British-controlled Trucial States would form a federation called the United Arab Emirates in 1971. Now truly independent (from the British) and suddenly oil-rich, this double-whammy of development saw an unprecedented and extremely fast-paced wave of nation-building activity—especially in emirates such as Dubai, Abu Dhabi and Sharjah within the UAE. There was an extraordinary demand in both white- and blue-collar job sectors, which brought in, what may be termed as the second generation of Indian expatriates in the UAE. This second generation, most of whom are still in the UAE, talk of their initial struggling years in legendary terms. Their social conversations are typically centered around “those times” when they were seeking jobs in a highly commercially fertile market with an extraordinary construction “boom”. Due to the conditions of “those times” miraculous turnovers happened in the lives of a few, who at some point or other shared a room or “bedspace” with each other and formed ever-lasting friendships that were cemented during their “struggling” phase. While all this sounds ancient, truly, these are only three or four decades-old stories—recent history to most of us historians.

This second generation of Indian expatriates, who landed in the UAE either through reference or through recruitment agencies in Mumbai, ended up having small businesses predominantly in the building materials and construction industries (interviews: Kumar, Purushothaman & Radhakrishnan 2020). They were also employed in the civil and mechanical engineering sectors as these were directly connected to the frenetic building activity of this region (interview: Doogar 2020). This second generation built their livelihood in the “boom” time associated with the decades of 1970s-up until the economic recession of 200-7-2009. Their successes, in fact, sustained a steady flow of both labor and specialists into the UAE for decades, and have truly transformed this desert—while also transforming their homelands and their families. In fact, it can be argued that what got built in the UAE has had a direct relationship to the exchanges and transactions of this second-generation Indian expatriates with the larger players in the construction and real-estate sector.

2 FOCUS AND METHOD

The current paper focuses on this second generation of Indian expatriates and their story, and their connections/contributions to the larger nation-building agenda of the visionary leaders of the UAE, with a special focus on the emirate of Dubai. Such narratives are either brushed aside while bemoaning the plight of the labor, or celebrating and/or critiquing the legendary and iconic development of places such as Dubai (Elsheshtawy, 2013).

2.1 *Interviews and subjects*

As a pilot study, a total of six individuals (henceforth, "subjects" or "contacts") were interviewed, and their oral histories recorded. Amongst the six, three were mainly involved in the sale or procurement of building construction materials or had set up businesses that connected with other such shops. We will call this group, "group A". One of these is the author's father-in-law (Purushothaman, henceforth P). The remaining two are friends with the author's father-in-law, who arrived in the UAE at different phases of this region's development (Radhakrishnan and Sajith—henceforth R and S). It is interesting to note that these friendships were made over the past 30–45 years only because of their dealings with building materials. They are neither from the same place in Kerala, nor do they belong to the same community or group. None of them were educated to deal with building and construction materials (the author's father-in-law, for instance, did his BSc in chemistry and was involved in teaching Maths and English in a tutorial college in Kizhur, in Kerala); however, all of them ended up in a totally different field that dealt with building and construction materials.

Along with the interviews of such individuals, the author also interviewed three individuals who are not directly connected to building construction and/or building materials, but are connected to engineering or engineering expertise—the other often neglected area of research when one thinks of the architecture or the built environment of a place. We will call this group, "group B". Of the three in this group, one of them is the father of the author's friend (Doogar, henceforth D), and the other two are contacts obtained from a local (unofficial) group made up of expatriates who are in the civil engineering field—most of them, interestingly, hailing from Hyderabad (Sama, Ravi—henceforth S and R).

In terms of method, semi-structured interviews were conducted with the subjects with the intention to mine a narrative that would be potentially rich in several aspects and could possibly reveal matters that are out of the scope of the current paper. Also, those (especially in group A) who were comfortable in speaking in their own language (Malayalam, in this case) could do so, thereby establishing a comfort zone and allowing for better expressions while recounting their nostalgic experiences. With Group B, the mode of conversation was predominantly English. In the case of one subject from Group B (D), the interview occasionally drifted into Hindi as per the subject's convenience.

As mentioned earlier, since this is a pilot study there could be several drawbacks and blind spots in the current paper. While the aims and objectives are clear, the methods to arrive at a narrative that binds everything still requires certain clarifications and rigor. Notwithstanding the said challenges, the present paper nevertheless makes an honest effort in making a decisive jump into this ocean of information to extract data that could tell a comprehensive story of this place—and the making of its built environment.

The three subjects from group A are primarily connected with building materials and have worked in several capacities; from accountants to storekeepers to sales representatives to showroom managers, and some even started their own business ventures (building material supply companies) after having gained experience in the building materials field for two to four decades (P and R). All three are still living and operating from Dubai. Two of the contacts came here during late 1970s (P and R), one candidate came as late as 2007 (S)—right in the middle of the great recession of 2007–2009. The oldest in this group, P, came to Dubai in 1976. R, in his 60s now, came to Oman first in 1977. S came to Dubai in 2007.

2.2 *Categorizations of the evolving data*

Several common categories (for both further research and discussion) were established after the six interviews were conducted, and the stories were reorganized to fit the general framework of the current paper. These categorizations are not final by any measure and might evolve into newer categories or systems as the research gathers more data and momentum. For the purposes of the larger research, the following four categories are devised for both the groups (A and B).

1. "In those days…"
2. Professional experience(s)
3. Claims and revelations
4. Transactions

The purpose of the above categorization is purely to reorganize the wealth of data that has been obtained through interviews (the shortest interview lasted 40 minutes, whereas the longest interview in one sitting went for more than two hours; another interview was spread over three to four days as per the convenience of the subject and accounted for a total of three and a half hours). In the following section, we shall go through some of the highlights from the three interviews from Group A. Further, considering the limitation of space, only the first two categories ("In those days…", and "Professional experiences") will be discussed in the current paper, along with suggestions of methods that may be employed for analyzing such data in the other categories listed here.

As the title of the category suggests, the first is a nostalgic remembering of the experiences of the subject—a necessary first step in almost all interviews (in both groups), to both assign a sense of importance, as well as purpose, to the interview. The second category deals with their professional experiences and affiliations in the Gulf region. This category starts revealing the underbelly of the design and construction field—the building materials merchants and companies—because of whom certain building materials start "moving" (this term is often used to indicate the most popular item, or the most wanted item) in the market, and certain geographies start getting associated with particular types of building materials. As this study is a pilot-study, the author has only begun to understand this rich data, and hence instead of analysis of this evolving data, presented here are suggestions towards developing a methodology to decipher and investigate the said data. As mentioned earlier, the conducted interviews were semi-structured and the subjects were free to use their native language or mother-tongue to tell the story.

3 “IN THOSE DAYS…”

This first category is named thus because of the number of times the subjects used the above term in the recounting their experiences. Most of their replies would invariably begin with “In those days…” thus ascribing, while doing so, a sense of a distant—perhaps a legendary past, to their endeavors and their personal stories. In the case of two subjects, this distant past is three or four decades old, and in the case of one subject, “in those days” refers to a decade old story. Despite the three decade gap between P, R, and S, certain common factors have emerged from the interviews that might shed light on the prevalence of a certain *doxa* (in Bourdiean terms) that enabled these subjects to come to the UAE in the first place—regardless of their regional background caste/creed or education. For instance, both P and R (the oldest in group A) graduated in the early 1970s in India. R was a commerce graduate (B.Com.) and he worked for four-five years in Kerala after his education—but soon developed an interest in the Gulf region— then popularly known as “Persia” in Kerala (Radhakrishnan 2020). Even now many from the older generation refer to the Gulf countries as Persia. Similarly, P graduated in 1974 with a BSc in Chemistry, and further educated himself with a higher diploma in cooperation commerce, banking and accountancy (Purushothaman 2020). He had no intention of coming to the Gulf. In fact, he even had an offer to work as an Assistant Station Master in the Indian Railways—a central government entity (ibid.). Getting a position in the Indian Railways was regarded as a highly fortunate occurrence in India—an attitude that resonated with “service to the nation” attitude during the immediate post-independence decades (Chopra 2003). S, the youngest in this group is also a commerce graduate who came here with a work-permit to work as an accountant in 2007. This is 2007 and unlike P and R, S did not have to go through Mumbai to come to Dubai. Sustained businesses with the Arab world had triggered a travel boom which had created four operational international airports in the relatively small Indian state of Kerala. It has also created a never-ending real estate explosion, investment in hospitality, retail, education, and health sectors in the relatively small state of South India. Now, aspiring Malayalees can travel to the UAE directly from home.

None of these individuals knew each other prior to coming to the Gulf or to the UAE specifically. None of these individuals came here to tacitly work in the building materials sector either—however, ended up doing so, predominantly, in the sales division of building materials.

Working in the “Gulf” or “Persia” was a thrilling prospect during the 1970s, especially in Kerala. Mass migration from Kerala to the Gulf countries had started in as early as the mid-1960s according to some experts (Sanandakumar 2015). Movies about Gulf returnees had further helped in creating an image of luxury and comfort associated with life after the Gulf experience. As Prof Irudaya Rajan from the Centre for Development Studies, Thiruvananthapuram, and a well-known expert in Malayalee migration studies of remarks,

> “The old Gulf Malayalee was a neo rich, semi-literate upstart who lands up at the airport sporting dark glasses and bell-bottom trousers with a National Panasonic two-in-one tape recorder in one hand and in the other a suitcase full of perfume, liquor and other goodies for his friends and relatives” (Sanandakumar 2015).

P recalls that around 20–25 people from his town (Kizhur) were already present in the UAE—some of them, his seniors from college, who had immediately gone to the UAE after their graduation (while he was searching for government jobs in Kerala). R on the other hand, landed in Oman and had travelled via sea from Mumbai. Mumbai used to be the point of departure for those interested in working in the Gulf. Most of the recruitment interviews—both walk-in and scheduled—were conducted in hotels where recruitment companies would set up temporary offices for several days to recruit hundreds of Indians to the Gulf nations. Why Mumbai was the chosen destination for all recruiters from the Gulf is a query that needs further research.

In 1970s Kerala, rags to riches stories of individuals working in the Gulf abounded; there were stories of men with hardly any educational backgrounds and working as drivers or such jobs in the UAE, marrying women who were highly qualified (such as doctors and engineers) from Kerala (Purushothaman 2020). Parents would happily offer their daughters to Malayalee men working in the Gulf—it mattered little in what capacity they were working in “Persia”—as long as they were in “Persia” it was believed that their daughters would be in safe hands (ibid.). There was a sense of luxury, comfort and security associated with the Gulf, which continues to this day. It was also considered glamorous to be in the Gulf. In Bourdieuan terms, a *doxa* was thus created. Doxa refers to an unquestionable orthodoxy that establishes itself across social space in its entirety, from the practices and perceptions of individuals to that of the state and social groups within it. Once established, a doxa operates as if it were an objective truth (Chopra 2003). In such a climate, only a little push or pull is needed for someone in Kerala to take that leap and head for the Gulf. Often such ventures are supported almost unquestionably by friends and family because of the obvious economic benefits that might result from such associations, to the group/family or even to the village or town in the long run. P fondly remembers how there were friends and relatives who helped, for instance in getting his shirts and pants stitched (through a tailor friend, who left other jobs to help this urgent case), or in the purchase of shoes, etc. when he had to leave for Mumbai at a short notice for a scheduled interview with a recruiting firm from Dubai.

4 PROFESSIONAL EXPERIENCES

This category is created to address the professional journey of the subjects after reaching the Gulf. It is in this category that we find data pertaining to prominent building material companies, moving materials, particular preferences for geographies from where such materials were procured, and certain preferences for people from certain geographies for carrying out specific types of jobs. The interviews also recorded certain "intelligent" and impromptu decision-making skills in the practices of the subjects while on their specific jobs. While such stories could be colored by a desire to create a legend out of oneself, the stories also spoke about the problem-solving skills of the Indian expatriates and the honesty and eagerness with which they approached problems, and hence the unwavering faith and dependency of the Arab world on them. While all the above will require individual attention and deeper inquiry—the space of the current paper will only allow the discussion of a few examples from each and the methods one can employ to analyze such data (based on all six interviews—three from group A and three from group B).

In terms of recruitment, at least three subjects spoke about preferences for individuals from certain regions for specific types of jobs. For instance, while Mumbai was the hub for recruitment companies mining the Indian market for both white- and blue-collar jobs—the companies would specifically turn to Pakistan for recruiting men for blue-collar jobs (Purushothaman 2020). Almost all the subjects speak of the drivers who were from Pakistan or from the Punjab province (Indian and/or Pakistan side), or from Afghanistan. These drivers would transport goods to as far as Iran and Iraq by road (Doogar 2020). Masons and carpenters were predominantly from Rajasthan and Uttar Pradesh in India (Purushothaman 2020). Plumbers, fitters, etcetera were from Bihar (Doogar 2020). Accountants, professionals in the sales department, storekeepers, clerks, personal assistants, typists—jobs that demanded a relatively better understanding of the English language—were predominantly given to Malayalees (Purushothaman 2020, Radhakrishnan 2020). Engineers (civil and mechanical) were predominantly from the Telugu-speaking communities of Andhra Pradesh. It is perhaps not surprising then to find this report of when Emirati and Indian experts and engineers in the UAE came together at a virtual event (due to COVID restrictions) on 15th September 2020, to pay tribute to the legendary Indian engineer, Sir M. Vishweshvaraya (Kumar 2020).

While recounting their professional experiences, the subjects mentioned certain geographies and certain materials that were prevalent during "those days." In the context of Al Rahmani where P was employed as the warehouse manager, some of the predominant materials or products that were moving during the late 1970s and early 1980s were: Pavismalt ceramic tiles (Italian product), Ideal Standard (in different colors) sanitary fittings from the UK, Bhushan GI Pipes from India, Charminar asbestos and plain sheets from India, chipboards from Greece or Spain, commercial plywood initially from Taiwan, Malaysia, and Indonesia (Purushothaman 2020). Film faced plywood came from Finland and Malaysia (Ibid.). P recounts there was only one material that came from China during those days, Camel brand roofing felt (Ibid.). One of the luxury items then was Formica—Al Rahmani had about 500–600 patterns—they used to come initially from Japan (Toyo brand) with floral designs. It was considered supreme luxury to have furniture made of commercial plywood and laminated with formica—and P remembers that there was one day when Sheikh Maktoum bin Rashid al Maktoum (the former Vice President and Prime Minister of the UAE and the Emir (ruler) of Dubai from 1971 until his death in 2006) had come to the warehouse to select Formica laminates for his palace. According to R, in Oman, ceramic tiles were imported from Italy and Spain in the late 1970s and into the 1980s (Radhakrishnan 2020). For plumbing, different types of pipes, soil pipes etcetera used to come from Japan (ibid.). During his time in Oman, R recounts that cement used to come from Ras al Khaimah and Dubai, since Oman did not then have cement factories. White cement was imported from Japan or Belgium. In the 1980s, cement started coming in from India as well (Birla cement and JK cements). Some of the Indian cement factories would eventually set up factories in the UAE for easier transactions, and to save time—one of the most crucial factors in the fast-paced development of the UAE.

5 CONCLUSION: TOWARDS A METHODOLOGY OF INVESTIGATION

As mentioned earlier, the data presented in the current paper is necessarily reductive and indicative of a pilot study. It is reflecting only the words and opinions of the interviewed subjects. All the data has not yet been checked for factual correctness, although mentions of certain common events or materials across the interviews can be considered as correlational evidence and hence true. Statistical records (from companies, offices, ports, etcetera) corelating to the obtained data will further help in identifying flows and patterns in the larger movement of both materials and manpower. Predisposition to certain geographies for certain job sectors in the building materials and construction industries of the UAE, requires a larger pool of data (through interviews and company records) for further clarifications and analyses. The materials and the geographies that they came from are important data that has the potential to reveal the larger political affiliations and global flows of materials and expertise in the latter decades of the 20th century up until the first decade of the 21st century (before the great economic recession of 2007–2009 seemingly stalled such global movements). The "moving" of certain materials during certain phases of the region's development could also be analyzed under the socio-cultural or even political associations or predispositions using a Bourdieuan framework of "field" and "habitus". Further, the methods of transactions—forms for permissions, orders, procurement, hand-written notes, type-written records of stocks, etcetera, between vendors, shipment officials, port offices, site engineers, project managers etcetera, could initiate a complex material-based reading. All of these and their wider implications need to be studied to better understand the larger and visible built environment of this region.

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An Indian engineer in the Middle East: South-South cooperation and professional collaboration in the 1970s

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ABSTRACT: This paper tells the story of a brief but dynamic period of professional collaboration between India, Iran and a few other Middle Eastern countries in the 1970s, through the personal experiences of one of the most celebrated Indian structural engineers – Mahendra Raj. The 1970s marked a shift in the global economic and political climate due to the oil crisis, initiating a sharp rise of wealth in many Middle Eastern countries. This resulted in an increased drive for modernization of infrastructure and intense building activity. Despite the heavy presence of large Western companies and their technical know-how, an emerging class of Indian technocrats fostered a unique exchange of professional expertise between India and the Middle East. Through access to Raj's archival construction documents and oral history, the paper reveals hitherto under-documented transnational political-economic, technical and social networks of exchange within the Global South.

1 GETTING STARTED

Arbita Housing (1977–9) was a large housing development designed for 580 units in 20 identical blocks located in Tehran. The building blocks of mid to high rise massing were designed for seismic forces in the region. Shear walls and flat slabs in concrete were adopted as the primary structural system. This project was designed by two Indian professionals, Mahendra Raj a structural engineer, and architect Raj Rewal, who were hired by the Iranian company Arbita. The French consulting engineering firm Socotec were the structural control consultants on the project. Arbita Housing was one of many projects Mahendra Raj was involved with in the Middle East that exemplified a fairly common phenomenon of bringing professionals from the Global South to work with management companies of the West. What Iran and the Middle East in general seemed to have witnessed in the 1970s was a transnational exchange of knowledge systems and technical processes between the developed and developing worlds creating a global synergy of sorts. Born in 1924, by the mid1970s Mahendra Raj's rich experience spanned from his work with Le Corbusier in Chandigarh, exposure with Amman and Whitney in the USA on significant large span projects ending with Minoru Yamasaki's project in Delhi, his consultancy to Louis Kahn's work in Ahmedabad and his engineering collaborations with many important Indian architects like AP Kanvinde, Charles Correa, BV Doshi, Raj Rewal to name a few. Mahendra Raj's work and experiences offer a unique insight into the formats of exchange that took place in the Middle East, particularly Iran, from the early 1970s till the Iranian Revolution in 1979. We use his projects and personal narratives to delve into this very specific geography of construction history.

What we learn from exploring Raj's experience is not conclusive in any way, nor are many of its connections documented in official or academic formats. Nevertheless, evidence through construction drawings and oral histories offers a lens into the deep connection between South Asia and the Middle East; of a professional exchange of technical building expertise that must be historicized and understood. The dominant and evident connection of Western (European and American) industrialized and developed nations as knowledge centres has often blurred the other exchanges, the domains of knowledge and technical expertise found in the Global South. The Middle East building boom of the 1970s, although largely under the dominant and large Western corporations, involved many South Asian consultancies and construction companies – the exchange was not only of unskilled labour as the popular narrative would have one believe, but of engineers, contractors, construction managers, and architects many of whom, like Raj, offered independent consultancy services and transfer of knowledge.

South Asian participation in the Middle East construction history of the seventies – through Raj's work and oral narratives – can be explored under three specific themes. First, the political and economic modalities that made possible such collaborations across national boundaries. Second, the manner of technical expertise and exchange provided by the engineering of Mahendra Raj as revealed in his archival drawings. Third, the social relationships fuelled by international networks of education, culture and history. Compared

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to his visionary and inventive contributions to modern building history, particularly in India, Raj's projects in the Middle East are unremarkable in many ways. Nonetheless they provide evidence of how economic needs fostered political ties and in doing so, made space for inventive partnerships. It is evidence of a unique transnational exchange and cross-fertilization of construction knowledge and techniques that found an interesting hybrid in this particular region in the 1970s. It is evidence of how colonial frameworks of education and social polity, incidentally, also facilitated new systems of exchange within the Global South.

2 NARRATIVES OF EXCHANGE: POLITICAL-ECONOMIC

The 1970s marked a shift in the global economic and political climate, when the oil crisis initiated a sharp rise of wealth in many Middle Eastern countries. It is well known that the migration of construction labour from South Asia to the Middle East started at this time. It was and has grown to be the reason why migrant population in the Middle East is more than its local population. The Gulf countries introduced policies to invite foreign workers because of their small workforce at a time when they were initiating building and infrastructure work after gains from oil wealth. They invited and accepted cheaper labour from South Asian countries, mainly India, particularly in the building industry. From 223,000 (Weiner 1982) in the 1970s to around 8.9 million today, Indians living in the Gulf form one of the largest concentrations of migrants in the world. In many of these capital-rich, labour-short countries the migrant population was more than the local in 1975 – 32.5% of the labour force comprised South Asians (Singh & Arimbra 2019).

Migration of unskilled and semi-skilled labour to the Gulf after the oil boom continues to date and forms the second-largest Indian diaspora after South East Asia. However, from the mid-1970s till the Iranian Revolution one saw an unprecedented exchange between Indian professionals (architects, engineers etc.) along with contractors and unskilled workers in the Middle East, predominantly Iran. This was on account of a new era of political, economic and social transformation in the countries of this region because of the global oil crisis. The new wealth from their rich oil reserves gave rise not only to a surge in the building industry – with the liberalization of national economies and the urgent need for modernization – but an assertion of modernity that attracted a global engagement of highly educated professionals.

Between 1970 and 1977 the GDP of Saudi Arabia, measured in monetary terms, increased by over 1000 per cent, the UAE by 800 per cent, Kuwait and Libya by 400 per cent (Kurbursi 1980) This presented fresh opportunities for trade, investment and exchange of both consumer services and professional expertise for India, a newly industrialized economy, like many others of the Global South after centuries of colonial oppression. In the decade leading up to this time both India and the Middle East witnessed an increased drive for modernization particularly through infrastructure development and construction, partially supported by development aid programmes and influx of Western "experts", and partially reinforced by foreign-trained building professionals returning to their home countries.?

In India the 1950s was more about consolidating its internal territory and politics. The 1960s saw a push towards industrial growth as well as service- and skill-building initiatives. It was also a period when many professionals travelled to Western countries, particularly the USA and UK, for higher education. The 1970s in India marked two decades of independence from British rule. Like many nations emerging out of centuries of colonial rule this time was marked by political and economic ties being formed between many developing nations, what is also characterized as the "South" in current literature, forging different identities and groups, for example the ASEAN, Commonwealth, NAM, and G-77. The first Asian Trade Fair hosted at the Pragati Maidan in New Delhi, India, in 1972 was a built expression of such an association, marking an era of national assertions of the developmental socialist state.

Narratives around modernity and development also emerged between some countries of the Middle East and?South Asia. The vision of Mohammad Reza Pahlavi (the last Shah or King of Iran) played an important role in pushing the modernizing development agenda and a pro-Western foreign policy in Iran. India and the Middle East (west Asia) region have ties dating back to ancient times. In addition to trade, flowing exchanges of culture and science took place between these countries. Following the end of colonial rule over this region, and the oil related boom in these countries, the 1970s thus saw a revival of ties between India and Iran, along with other Middle Eastern countries. The Indo-Iranian joint commission and Indo-Iran cooperation ties expanded significantly in this decade with the signing of an Indo-Iranian agreement for cultural exchange in 1973, the Indian foreign minister's visit in 1974, and then Prime Minister Indira Gandhi's visit in 1976. Several efforts at technical cooperation in the fields of science and technology were carried out from 1972 by the planning commissions of both countries. India's relations with Saudi Arabia and Kuwait were also fertile during this time in the fields of technology and trade (Faruqi 1986)

On the professional front, by 1970 Iran had also convened the First International Congress of Architects in Isfahan (Sedighi 2020) In 1974 the Second International Congress of Architects was held in Persepolis, Iran. At both events Indian architects BV Doshi and Ranjit Sabikhi, (Sabikhi 2020) among others, were also involved. The following years witnessed a greater collaboration between the two countries with growing instances of exchange and transfer of materials and expertise. Western involvement in the professional sphere was soon substituted by professional consultants from South Asia. Architects, contractors, companies, and even government officials from Iran and the Middle East travelled to India to interview and hire consultants. Mahendra Raj, as an engineer of note practising in New Delhi, was part of this transnational wave that focused on greater collaboration within the geopolitical networks of the Global South.

Mahendra Raj's engagement in the Middle East started with the Kuwait National Assembly project competition in 1972 that he worked on with BV Doshi (unbuilt).? By 1975–6 an array of projects came his way, ranging from the Pahlavi University Dormitories and Gymnasium Complex, with Indian architect Ranjit Sabikhi and the Iranian architect Modam, to a large infrastructure project, the Intake Jetty, for a desalination plant in Oman, with Rodio Hazrat (Lall 2015) Having engineered several major commissions that had started to define modern Indian architecture (including large-scale stadia, theatres, high-rise towers, hotels, offices, factories, and several pathbreaking buildings at the Asian Trade Fair project) along with his experience in designing ports and harbours, Raj's work in the Middle East grew to consume much of his practice in the few years from 1975–9 continuing into the 80s. In several projects Raj also was the primary consultant or was offered independent projects such as the Museum and Cultural Centre, Karmanshah (unbuilt), in 1976–8, with Iranian architects Modam and Michel Ecochard, and the Arbita Housing Project. Beyond these projects Raj worked independently alongside Kavinde, Rai and Chowdhury in Baghdad on the Water Research Centre (1977–84); and the Social Insurance Building (1977–9), Jeddah, and the Medina Mosque (1980–1) with Ranjit Sabikhi and CAC (Consulting Architectural Corporation, Jeddah) (Mehta et al. 2016) Raj's last work in the Middle East was the Indian Embassy (1988–9) with Ranjit Sabikhi. Several of these projects also designed by Indian architects like Raj Rewal, AP Kanvinde, BV Doshi and Ranjit Sabikhi reveal the growing involvement of Indian professionals in the region and the scale of South-South cooperation that emerged from the political and economic modalities that developmental states in different countries set up.

It is significant to record that Raj serviced all these jobs in the Middle East through a newly incorporated private limited company MRC (Mahendra Raj Consultants) to avail of the Indian Government's tax initiatives. Since the money and volume of work from the Middle East was high, and many people had started doing work there, the Indian Government aided this process by making income by incorporated companies tax-free. This was done to incentivize an inflow of foreign currency into the country's low reserves. In response these professionals incorporated their earlier individual/solo or proprietary practices to avail themselves of this benefit. Mahendra Raj's new company, formed in 1976, even today reminds us of that fertile time of transnational transfer of technocratic knowledge that allowed unseen economic mobility in the Indian middle class.

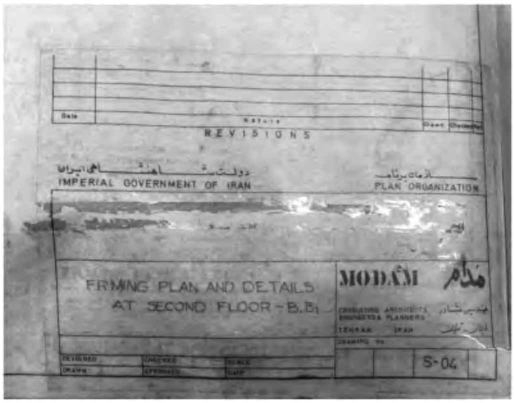

Figure 1. Mahendra Raj Archives, Drawing from MODAM, Project Unknown with an Imperial Government of Iran stamp.

3 NARRATIVES OF EXCHANGE: TECHNICAL

For the kind of outstanding work Raj had already achieved in his career by the early 70s (Mehta et al. 2016), his work in the Middle East, though sizeable in numbers and economic gains, is rather unremarkable. Much of his work before and after the Iranian/Middle East phase is visionary and inventive and forms a significant contribution to modern building history, particularly in India. It is interesting that his own hesitation in highlighting the mid-1970s as an important phase of his career corroborates the archival records and drawings we found of the projects in Iran and other Middle East countries from that time. Nonetheless three interesting transnational processes are revealed in this time of intense building activity in this region: First, fuelled by the oil wealth there was a rush of building activity with too many projects but too few trained professionals in Iran and other countries of the Middle East. Indians proved to be useful here and could provide technical services required to execute these large projects as they were better value for money in comparison to their expensive Western counterparts who already had a presence in this region in the form of large companies and consultancies.

The second is related to contracts; though economically beneficial, many of the projects in the Middle East, such as the Social Insurance Building and the Medina Mosque, did not require the Indian consultants to visit the site. As the project teams included local architects and construction management firms from Europe, the Indian professionals (Raj and Sabikhi in this case) never saw the structure; they merely designed, sent drawings, and travelled, if necessary, for coordination meetings (Figure 1).

Raj's archives reveal another interesting part of this contractual exchange between Iran and Indian building professionals at that time: some drawing sets without building names or names of consultants. These incomplete title blocks however bore a stamp of the Imperial

Government of Iran and were not Raj's projects. These were probably drawings of buildings that he may have provided technical help for, with proof checking or designing/detailing. "In those years with the rush in building activity, it was common for Iranian people from small or large construction companies or even government ministries to come to India to fulfil project requirements like creating technical drawings, proof checking etc. without the need of the consultant ever going to the site. There were also many companies who travelled to India to interview consultants for a more active role in potential building projects in Iran" (Raj pers. comm.). This is an oral history and undocumented account of how professionals from India were being hired to fill the huge gap of technical consultants in the building industry of Iran. The need and speed of construction work necessitated a South-South collaboration that many Indian professionals like Raj fulfilled with their technical knowledge and expertise.

The third and most important transnational process with respect to technical exchange is related to construction systems and processes that defined the parameters of design and the choice of materials. Materials and techniques found an interesting hybrid of the West and East in the context of the Middle East. Concrete became a material of choice as it was fast to build with the mechanized technology available from the Western companies. According to Raj, large moving form technology had become popular for its speed of construction in that period, despite higher costs, and had been brought into the region by German and Swiss construction companies. What is well known is that the high construction cost was offset with cheap labour from developing countries. However, less known is the fact that there were South Asian professionals such as Raj who adapted Western building technology to the seismic requirements for Iran (Figure 2).

The Arbita Housing project in Tehran is a case in point. Under French company Socotec's "structural control" Mahendra Raj's newly incorporated MRC Pvt. Ltd. provided the design and drawing work for building in an earthquake-prone region. Iran at that time had still not developed adequate codes for earthquake resistance in structures. With Raj's experience of over a decade in India, which is also high in seismicity, he had the knowledge required, and his expertise at taking on structural challenges was well known by then. For Arbita, Raj proposed shear walls and flat slabs in concrete which were adopted as the primary structural system. This is an interesting example in construction history where the use and transfer of technical knowledge in a nascent modern building industry was gained from the expertise of professionals from the South. Even though Raj, like other Indian professionals, worked with or under larger corporate construction players from western Europe, they nevertheless provided key construction techniques and knowhow to the Middle East, powered by experiences in their own country. In Arbita's case, Raj was already familiar with shear wall systems which he had used successfully in many projects back home (Raj 2020) (Figure 3).

Figure 2. Mahendra Raj Archives, Part Drawing, Arbita Housing, Tehran (1978) Typical Title Block showing the consultants involved in the Project.

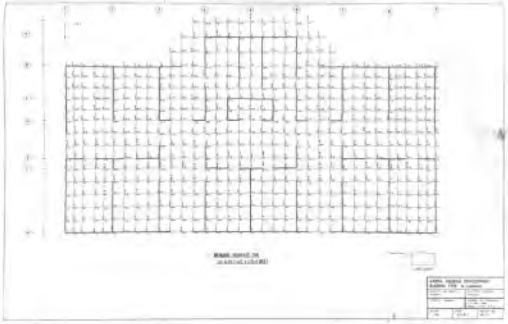

Figure 3. Mahendra Raj Archives, Drawing SK-33, Arbita Housing, Tehran (12 August 1978) "Sketch" drawing for foundation bending moments. Drawings such as this were made at 1:50 scale for proof checking, with different loading conditions for seismic forces.

Raj's archives reveal drawings (presented in *Sketches*) with seismic calculations and options to fulfil needs of construction in Iran that had to be proof checked and approved by Socotec before he could proceed to make construction drawings.?The "sketches" were a whole new series drawn systematically to prove how each part of the building would respond to the different loading directions, forces, and moments at play in case of an earthquake. These A1-sized drawings were sent to local offices in Iran and sometimes to its French headquarters for proof checking by Socotec. This entailed frequent travel to Iran and France by Raj himself to justify his seismic design with detailed calculations and idealization.

The "sketches" are rigorous and precise but beautiful drawings, with Raj's technical insights and finesse, made in large numbers to provide an earthquake efficacy to the structures he designed in Iran. They abided by, and?translated a rigour of design done previously on A4 size grid paper to a new framework of representation drafted on larger tracing sheets. This shift in practice of recording moments, seismic forces, on each part of a building on tracing at 1:50 scale indicate important instances of exchange between Indian professionals and consultants hired in Iran. Further, the elaborate drill of proving the structural validity to the French proof checkers also necessitated Raj to create in-house computer programmes despite very limited resources in an era when computer technology was still in its nascent stages.

Later, Tehran formed a municipality and adopted the American Building Codes which were not in favour of, or familiar with, complete buildings in shear walls. This meant additional work to get approvals from the municipality in Tehran. In one of his accounts Raj recalls having to make more drawings and computer calculations for which he sent his engineer from Delhi to Dehradun, where a better computer system was available, to generate calculations to present to the municipality. This was all in vain as the Revolution was soon to break and the building and these designs did not see light of day.

From Raj's anecdotes about the attitude of the Western and Eastern professionals in the Middle East, "The western consultants and contractors preferred more material and less labour, and the Indians preferred less material and more labour." This he said was "because the westerners were interested primarily in speed of work and Indians in the efficiency of resources and design" (pers. comm.). Raj's work has always revolved around crafting structural solutions. Structure has been to him a living, dynamic system that is resolved with grace, coherence, and minimal use of materials. This attitude also embodied the conditions in India post-Independence where resources were scarce, and labour was plenty. In the Western context his work in Amman and Whitney, where he developed this attitude to structure, was also about understanding the art of engineering. The Middle East, despite its exciting global engagement, was a corporate affair where time was the paramount player. Structure for the Western managers was a static system, that needed to be constructed quickly, with their mechanized technology, involving unskilled labour from the Global South.

The conflict of professional attitudes is highlighted in Raj's account of the Social Insurance Building in Jeddah that he designed with Sabikhi. Together, the two eminent professionals from India designed a transfer girder to create a large-span structure and clear space on the lower level for a shopping complex with offices above. Elegantly crafted transfer girders had been used successfully by Raj in his work in India, notably in the Great Insurance building and the Akbar Hotel in the 1960s and in 1977 he was designing a similar structure for the Maurya Hotel in Delhi. However, the Indian design was considered too complex and specific to suit the standardizations of the construction method preferred by the prime consultants, CAC, and hence was ruled out for an easier and faster building option – a large deep rectangular beam – depriving the project of any innovative design possibility (Figures 4, 5).?

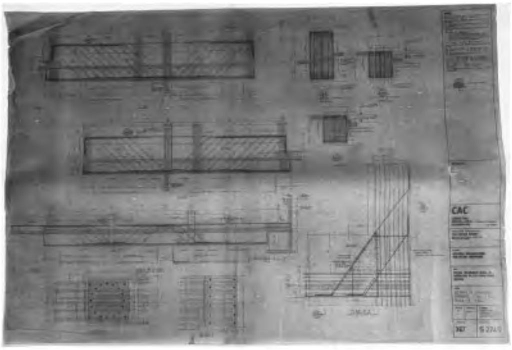

Figure 4. Mahendra Raj Archives, Drawing 124. HM.59.D, Maurya Hotel, New Delhi (26 July 1976) *Details of Girder-Figure1* MRC Archives, Drawing S224-2, Social Insurance Building-II, Jeddah (6 June1977) *Details of Transfer Girders*.

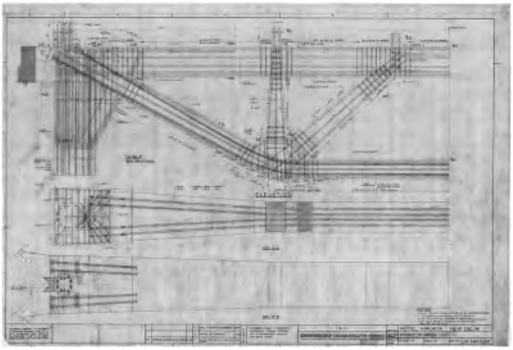

Figure 5. MRC Archives, Drawing S224-2, Social Insurance Building-II, Jeddah (6 June 1977) *Details of Transfer Girders*.

However, the exchange of design and methodology among non-Western professionals continued to flow both ways. There was learning of construction methods that had been used in Iran and other Middle East countries that were then applied in India. Raj talks about the popular use of the pre-cast slab system in Iran – a local technology primarily used with arches and constructed by semi-skilled labour. He introduced the pre-cast system in India because of its efficiency and ease. Pre-cast T-section battens that carried hollow blocks as a slab system was one of the techniques

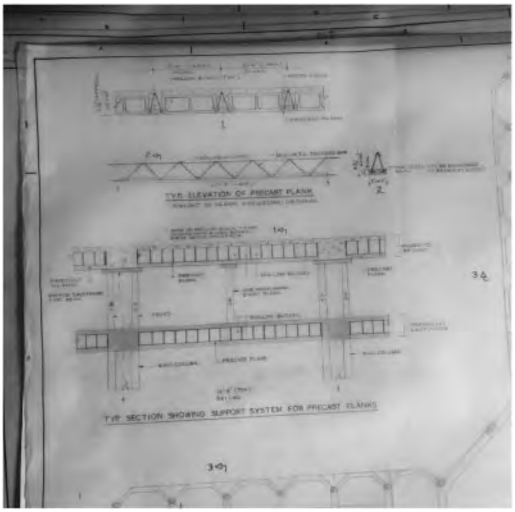

Figure 6. Mahendra Raj Archives, Part Drawing, Maurya Hotel, New Delhi (26 Aug 1976) Typical Section and Elevation details of Precast Planks.

that Raj used in a few of his projects: The Maurya Hotel in New Delhi (1977), and the JP Hotel in Agra (1993). Customizing both the T-sections and hollow blocks between cast beams helped avoid large floor-slab concreting thereby saving material and time. It also shows the emergence of a two-way exchange where Raj's exposure to some of the local Iranian construction techniques were brought back to his Indian practice. It is important to note this technology was absorbed on visits to Iran and were not part of any project Raj was involved in. It was an assimilation of a construction practice nurtured in the Global South that respected material economy and craft (Figure 6).

4 NARRATIVES OF EXCHANGE: SOCIAL

Interviews with Mahendra Raj reveal how most of his professional colleagues, architects, engineers, construction managers, and even other designers had some work in the Middle East at that time, how they travelled together frequently and slowly expanded their network to their friends back home. The intensity of engagement was such that Raj's practice grew and was almost completely sustained for a couple of years in the mid-1970s by the work he was engaged with in the Middle East, in his case particularly Iran.

This period really speaks about an economic engagement but one that was fostered by prior social connections and that also led to the start of new networks. Even though companies from the Middle East started coming to India and interviewing consultants, the first breakthroughs happened because of global systems of education and shared professional histories. Raj's infrastructure project in Oman was with the company Rodio Hazrat. His first work with them was the Great Insurance building project in 1960 in Bombay (present day Mumbai). He designed several ports and harbour projects with the company in India in the later parts of the 1960s and then 1970s.

Rodio Hazrat took Raj to Oman in 1975 for the Intake Jetty of a desalination plant, his first realized project in the Middle East. This was his entry into the region. At the same time architect Ranjit Sabikhi brought him his first building project in Iran of the Pahlavi University Dormitories (Sabikhi 2020) Much of the work Sabhiki did outside India went back to the social associations that were formed during his years of graduate study at?Liverpool University. He had kept in touch with colleagues from Iran, Saudi Arabia, Singapore and Hong Kong among others, despite a communication system that was not as seamless as today. The Pahlavi University Dormitories project was carried out with the Iranian firm Modam, an association he had made in Liverpool It was common for clients to hire local architects who would then subcontract their work to architects and consultants from India. Soon Modam was hiring Raj independently for the Gymnasium Complex at the Pahlavi University and later, a Museum and Cultural Centre at Karmanshah. Similarly, the Social Insurance building in Jeddah was also a collaboration with Sabikhi and CAC (later renamed Jamjoom Consultants). The Jamjoom brothers were Sabikhi's colleagues at Liverpool as well and invited him to work on this building and others.

Many of these works remained unbuilt but what emerges is a significant social narrative of personal associations developed either in practice or on account of Western educational exposure that connected Middle Eastern and Indian professionals. Sabikhi's Liverpool education is the reason why he was contacted by his Iranian classmate for help and support. Mahendra Raj's project in the 60s with Rodio Hazrat resulted in a close professional relationship and led to him being brought in as a consultant for their projects in Oman.

Finally, what also impressed Raj was the professionalism and systems of project management in his projects in Jeddah that were very different from the Indian reality. Despite his substantial experience, from working with Le Corbusier in Chandigarh, to working in the USA with Amman and Whitney, and then over a decade of practice in India (Mehta et al. 2016), the Middle East stood out in his mind for the manner in which projects were handled, and the level of professionalism expected by all concerned parties – engineers, architects and contractors. Construction management sourced from Europe and sophisticated engineering design services sourced from India for projects in the Middle East highlight how technical processes and knowledge systems between the developed and developing worlds created a global synergy rarely seen before.

Raj aspired to that level of management for projects in India and soon started a construction management wing in his company in association with a fellow professional, Tikam Wadhwani. Wadhwani and Raj's association started with projects in India for the Delhi Cloth Mills (DCM) in early 1970s. Tikam was the construction manager representing DCM and was subsequently absorbed by the building boom in Iran where he worked and lived. It was on one of Raj's visits to Iran that their friendship developed and resulted in the incorporation of MRC's subsidiary ICMC (Integrated Construction Management Consultancy Private Limited) in 1979 – the year all work abruptly stopped in Iran because of the Revolution. Raj aspired to introduce in India a construction management service similar to what had impressed him – a service that defined construction schedules, managed drawings, and became an agency that all?engineering/architectural services along with the contractors would be answerable to. Post this decade the 80s saw Raj absorb and manifest his experiences in the Middle East as he completed the remaining projects in Jeddah and Baghdad. He finally returned to the region 10 years later with Sabikhi again for building the Indian Embassy in Kuwait in 1988-9.

5 CONCLUSIONS

The idea of a rigorous and concentrated spell of technical exchange between India and Iran, and more largely speaking, South Asia and the Middle East, shows us an interesting time in construction history that is relatively under-documented. Despite the specificity of the account of one Indian engineer and a few related interviews, this period of the mid-1970s has potential for study and further research to excavate exchanges between two regions of the Global South. What emerged is a trajectory of history quite different from one which is oft heard of – the construction help given by the Western developed nations to the developing ones. Rather, there was also a prolific exchange between developing nations, widespread enough to acknowledge and theorize. It also reveals that though controls on development were certainly dominated by large Western agglomerates, the domain of technical expertise and knowledge tended to be an input of the professionals of the developing world breaking the popular narrative that South-South cooperation was largely a migration of unskilled labour.

This brief period also talks of the nourishing exchange between two nations, regions, and the struggle to regain lost and impoverished identities in a post-colonial time. This belies many narratives not in the least the communal animosities between Hindus and Muslims that have been touted and politically instigated for over a century. In fact, it possibly reveals an historic respect and understanding of cultural connections far back in time. The 1970s was certainly a time rich in such associations that were to realign nations and people who had been estranged under colonial politics.

It is important to revisit the International Congress of Architects held in Iran, mentioned earlier in the paper, as an exchange that led to the *Habitat Bill of Rights*, a CIAM-like charter to the UN Conference on Human Settlements in 1976. This bill, proposed by Iranian, Turkish and Indian architects among others, has played a crucial role in discourses on regionalism and its relationship to tradition and modernism, proposing culturally appropriate forms and standards, particularly of housing, to counter the international style propagated during late modernist times by Europe and America (Westbrook & Mozaffari 2015) With much of this region having a rich heritage and tradition in building trades, skills and materials, there was a need to also stake its claim in the global dialogues of architecture, planning, technology and design, and reposition its cultural foundations in a modern rhetoric. Cultural projects, in the realm of institutions like health education and government complexes, but also in mass social housing were addressing issues pertaining to regional culture, social identity, human habitat and housing needs staking an identity for the Global South against traditional colonial frameworks of knowledge and identity

The last narrative the paper interrogates are the social networks that brought this exchange forth. What this has revealed is an interesting flow of people and how their interactions brought them to the juncture of the building boom in the Middle East. That colonialism played an important role here in promoting friendships between non-Westerners, particularly in Western educational institutions, cannot be overlooked. Indeed, the widespread obsession with the field of engineering in India, which was also an outcome of British rule and their need to create the infrastructure to rule over water and land of the colonized, produced a large number of engineers in India. Engineering colleges were set up as a priority over other disciplines and became the most lucrative and respected jobs thereafter. This phenomenon created an entire generation (or even two) of engineers who would later take their experience to the outside world, in this case to the Middle East.

In the final analysis, while a building boom made the Middle East a hotspot of economic interest, it also brought together different agencies from around the world in an unusual set of relationships. It formed unique transnational corridors of construction, which revealed that indeed globalization is not a recent phenomenon. But more importantly the narratives that emerged from this exchange during the 1970s belie certain dominant paradigms of knowledge transfers and suggests South-South collaborations as an important part of the global construction history. The story of the brief but prolific interaction of engineer Mahendra Raj from India in the Middle East in the 1970s helps open a small and specific lens into this phenomenon.

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History of Construction Cultures – Mascarenhas-Mateus & Paula Pires (eds)

Prefabricating non-alignment: The IMS Žeželj system across the decolonized world

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ABSTRACT: The IMS Žeželj system was arguably one of the most successful prefabricated housing systems of the post-war period. However, it remains mostly unknown within construction history, because of its "peripheral" origins and distribution, which circumvented the imperial centers of the Cold War. Invented in socialist Yugoslavia in 1957, it was widely exported across Cold War divisions, especially to member states of the Non-Aligned Movement. A technology with deep colonial roots, prefabrication was recast as a tool of anticolonial solidarity, linking Europe's semi-periphery, with its own history of imperial subjugation, and the recently decolonized countries in Africa, Asia, and the Caribbean. Created by the Yugoslav constructor Branko Žeželj, the IMS Žeželj system was reminiscent of Le Corbusier's *Maison Domino*: a skeleton consisting of prestressed pillars and slabs. Prestressing technology, widely applied in the construction of large-span structures, was the system's key feature, one that had been rarely used in mass housing.

1 INTRODUCTION

Although the use of prefabricates can be traced back to antiquity, the modern history of prefabrication is often linked to the expansion of timber and iron industries in Britain and the United States of America in the 19th century. As iron was largely reserved for the architecture of urban areas, such as Thomas Telford's St Katharine Docks in London, 1828, or the cast-iron buildings of James Bogardus in the USA, timber became a material reserved for remote rural areas, especially for the housing of settlers in the new colonies during the gold rush in North America and Australia. It is widely accepted that the first known application of fully prefabricated construction was that of the "Portable Colonial Cottages for Emigrants", better known as Manning Houses, after John Manning, a London-based carpenter who designed them. These were advertised and sold to Australian settlers from 1830 onward and were the first fully prefabricated houses made of wood, the aim of which was to be assembled fast and transported far, to areas that had no infrastructure, trained workforce, or industrial production. As a "pioneering stance of colonialism being given an up-to-date technical base, an example of what has been aptly called 'the technology of colonial expansion"' and "an early manifestation of the industrialization of the building process and (…) the reciprocal relationship of the mother country to the colonies" (Herbert 1972, 272, 274) the Manning Houses, and consequentially the technology of prefabrication, are burdened with the legacy of colonial expansion and its policies.

The technology of prefabrication in the socialist countries of Europe developed from very different origins. Except for interwar housing in Czechoslovakia and the USSR, there were only a few modest experiments with prefabrication in other Eastern European countries. Mass prefabrication emerged in these countries only in the scope of post-World War Two redevelopment and the new welfare policies of mass housing. The Yugoslav IMS Žeželj prefabrication system was no exception, emerging from the post-war hardship and a conscious effort by the Yugoslav leadership to pursue independent development. Branko Žeželj, one of Yugoslavia's most renowned engineers, designed the IMS Žeželj prefabricated system taking into consideration the material and labor limitations in post-war Yugoslavia, relying on concrete as the most affordable modern material, which did not require a highly trained workforce on the construction site. The system incorporated the accompanying assembly equipment, as well as simple training procedures. The situation was similar elsewhere: the same epithets – lagging, traditional, un(der)developed, non-industrial/craft-dependent economy – were used to describe the proverbial *turning point* wherever industrialized housing production and prefabrication were implemented, regardless of the socio-political system: whether in France and Sweden, or in the Soviet Union, Czechoslovakia, and Yugoslavia. The technology was immediately put into mass production to help alleviate the housing crisis in Yugoslav cities, but it was soon also exported for various purposes: as a form of post-disaster relief, as technical assistance, and for commercial purposes. The system was used

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in Hungary, Italy, Austria, Bulgaria, Russia, Georgia, Ukraine, China, Cuba, Egypt, Ethiopia, Angola, and the Philippines, with anecdotal evidence of possible usage in Libya, Iran, and Argentina, which are yet to be confirmed. The system came to be approved for use in an even larger number of countries, being officially attested and verified in Yugoslavia, Hungary, Italy, Austria, USSR/Russia, Uzbekistan, Cuba, PR China, and the USA. This paper will focus on the exports of the IMS Žeželj system to Ethiopia, Cuba and Angola, countries to which it was exported through all the above-mentioned modalities. Here, prefabrication was manifested not only as a material practice, but also as an avatar of the Yugoslav political system, promoting an alternative, self-managed development path, and independence from imperial incursions. It had always been the intention that exports of the system would be used in a variety of ways, from mass housing to schools and administrative buildings. The scale of application differed in each country: in Angola only two experimental buildings were completed, while Cuba imported three prefabrication plants and built another five, implementing the system for mass housing across the country. This paper will discuss the mechanisms that enabled these different scales of application.

2 STEMMING FROM A CRISIS: THE ORIGINS OF THE IMS ŽEŽELJ SYSTEM

In the mid-1950s, the government of the Federal People's Republic of Yugoslavia (FPRY) initiated an ambitious program to develop the construction sector. The country's post-war reconstruction in the previous decade had been an unmitigated success, and the economy became one of the fastest growing in the world, but the construction industry still lagged behind other areas of the economy. This lag occurred because the construction sector and the accompanying industries were designated a "service" to other economic activities, particularly to heavy industry, which was considered the backbone of modernization and development efforts.

Construction relied on traditional technologies and crafts, especially for projects that were not related to new industrial or transportation facilities (Jovanovic, manuscript). However, around 1955, as the economy switched to a fully self-managed organization, a major new field of capital investment was initiated: the infrastructures of the so-called social standard. It included the construction of mass housing with complementary services, the networks of educational and healthcare facilities, and road and transport infrastructure. To achieve these goals the construction sector had to consolidate, modernize, and industrialize. The country's leadership decided to take the path of typification, standardization, and prefabrication, similar to the processes undertaken by other European countries on both sides of the Iron Curtain. This was a conscious decision, based on an assessment of the country's available educational and industrial resources, skills, and international connections, as well as the previous experiences of other industrial nations, which could be used to predict costs and avoid mistakes (Figures 1 and 2).

Figure 1. The concept of the IMS Žeželj system. Source: Sistem IMS, 2.

Between 1955 and 1957, the state allocated funding for a variety of competitions in the field of housing. In 1956 a call for typified multi-storey housing was issued, followed in 1957 by a call for innovation in the field of structural systems for housing. In 1957, the Federal Assembly of the FPRY enacted the Resolution on the Prospective Development of the Building Sector to systemically support investments and enhance scientific research. Owing to these investments, the IMS Žeželj prefabricated system emerged, alongside dozens of prefabrication systems developed by different companies and institutes across the country, which were later applied in housing construction, but also adapted for other typologies, such as healthcare, administration, and education. The government's developmental strategy aimed at creating and applying as many domestically produced products and technologies as possible. Yugoslavia extensively relied on (and later also offered) technical assistance via the United Nations in a manner that always involved strategic planning by the ministerial bodies in charge, with an eye on potential further advancement of the local construction sector. The experience of international isolation provoked by the Tito-Stalin split in 1948 and the subsequent Cominform Resolution motivated the government to look inward and to rely on its own resources. This resilience materialized in homegrown technologies such as IMS Žeželj, as a strategy of minimizing the import of foreign construction methods and equipment. This was also motivated as a way of avoiding a foreign trade deficit, and even more importantly of reducing the potential dependence on foreign patent rights. These were used whenever Yugoslav construction companies appeared on foreign markets, especially in former colonies, and were presented as an added value in facing the common adversity.

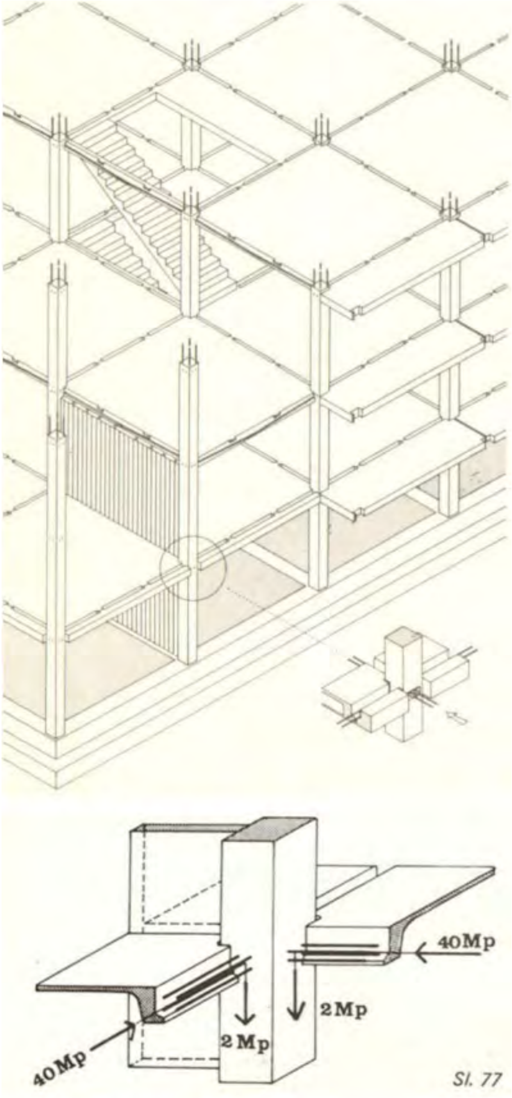

Figure 2. Model of the Lixeira-Luanda experimental housing, developed as part of the technical assistance for Angola in 1976. Source: personal archive of Dr Ivan Petrovic.

3 YUGOSLAV CONSTRUCTION ABROAD: EXPORTING KNOWLEDGE AND EXPERIENCE, TRADING AND SOLIDARIZING

The Yugoslav construction sector already began to export in 1952, although the country was still suffering the consequences of the Cominform crisis. At the height of international isolation from the rest of Europe, export markets were found in Syria, Turkey, Greece, Pakistan, Egypt, India, Lebanon, and Paraguay. Neither the government nor the construction companies hid their motivations: the country needed foreign currency to pay off foreign debts, while the large self-managed construction sector needed commissions to survive. During the post-war reconstruction (1944–7) this sector's capacities grew, as the country prepared for the next phase of infrastructural investments, but the crisis during the period between 1948 and 1953 left the nascent capacities underutilized. The appearance of various Yugoslav companies in foreign markets thus predated the founding of the Non-Aligned Movement (NAM) by several years – even if one considers the 1955 Bandung Conference as its starting point, rather than its official founding summit in Belgrade in 1961. From the start, these foreign markets transcended the Cold War divisions and alliances, thus pointing to the direction that Yugoslav diplomacy would follow in the decades to come. The economy of the new socialist country was still weak, and it could not compete with the developed countries, so it had to look elsewhere: the former territories of the Ottoman Empire and the new countries of the emerging decolonized world, which – in the opinion of Yugoslav officials – were experiencing similar challenges to Yugoslavia's own. However, research so far has shown that, besides providing the most affordable offers, the Yugoslav government made sure that foreign projects went hand-in-hand with friendly diplomatic relations: the construction was covered by bilateral inter-state agreements, and, depending on the country, financial and technical arrangements – favorable loans, credits, assistance, exchanges, etc. – were made available. Construction was just one part of the carefully planned and negotiated appearance of the Yugoslav economy on the global markets: documents on exports-imports of agricultural goods are often found side by side with foreign contracts for banking services or for the construction of bridges and ports (AJ, F130, F225, F574).

The export of the IMS Žeželj system followed a somewhat different logic: as a public institute, the Institute for Materials' Testing of the People's Republic of Serbia (Institute IMS), where Žeželj was employed, technically did not possess production lines. Instead, it simply sold patent rights to construction enterprises (such as Napred, Rad, Komgrap, Trudbenik and many other such enterprises across Yugoslavia) to use their system, and it provided assistance in setting up production lines. A similar pattern existed with exports; these only had to be administratively routed via the Chamber of Commerce and logistically via one of the licensed organizations representing Yugoslav companies abroad: Unioninženjering, Montinvest, Invest-Import, etc (Figure 3).

By 1967, when the earliest exports of IMS Žeželj technology discussed here occurred, Yugoslavia's construction sector was working at full capacity. The investments made by the government in the 1950s began to pay off, and around 40,000 IMS apartments were either in the process of being built or in the preparation phase across the country. The system was advertised from the onset as a fast and rational solution for the housing crisis, applicable in unfavorable

Figure 3. Experimental construction site of IMS Žeželj technology in Block 2 in New Belgrade, Serbia, ca. 1960. Source: Institute IMS archive.

circumstances, for example in areas which lacked a trained workforce or construction materials. The system was developed and patented in 1957 by the civil engineer Branko Žeželj, who was by then already well known for his bridges and the prestressed dome of the Hall 1 of the Belgrade Fair. Žeželj developed the system based on his experiences and extensive knowledge of the situation in the country: the (lack of) resources such as cement and iron, modest industrial capacities, the quality of construction materials and methods that were largely dependent on craftsmanship, as well as the (lack of) skills of the workforce, which mostly originated from the countryside. The system was developed under the auspices of the Institute IMS and was extensively elaborated and enhanced by the work and research of Žeželj's coworkers in several of the Institute's departments. It was precisely this collaboration that was the turning point for the system's acclaim among professionals, making it the most successful and popular among architects in Yugoslavia, primarily due to the flexibility of design that it offered. The system is skeletal, consisting of four pillars, each one to three storeys high, and a square waffle slab spanning 3.00 to 7.20 meters (Figure 4).

Prestressing tenons are positioned inside the pillars and on the side of the slab, post-tensioned by a pressure of 40 MPa horizontally and 2 MPa vertically (Figure 1). The system was at first envisioned as closed prefabrication, but as the number of orders grew and the production circumstances evolved, the variety of architectural designs increased, and the system was remodeled and reorganized to better facilitate the creative process. IMS Žeželj became an open system, which meant that structural elements (slabs, cantilevers and pillars) could be ordered and assembled completely independently of the envelope, which in turn could be designed however the architects envisaged. However, if required, envelope elements, such as spandrels and walls, could be ordered as well, in addition to such components as staircases, bathrooms and staircase shafts, which the system's creators dubbed "haberdashery" (Figure 4). Finally, the system was envisioned and promoted as socially responsible, meaning that with very little training, even an unskilled workforce could participate in the assembly process. The elements could be transported by trucks for ranges up to 100 km, or an unlimited range by railway and ship, and the system could be utilized even if there were no permanent plants in the vicinity of the construction site, through the establishment of "polygonal" (on-site) prefabrication (Figure 3). The pre-casting production line was made of durable elements, usually high-quality steel, allowing it to be used multiple times. Prior to the first exports, all the described features were successfully applied on the construction sites within Yugoslavia, most extensively in New Belgrade (Figure 5).

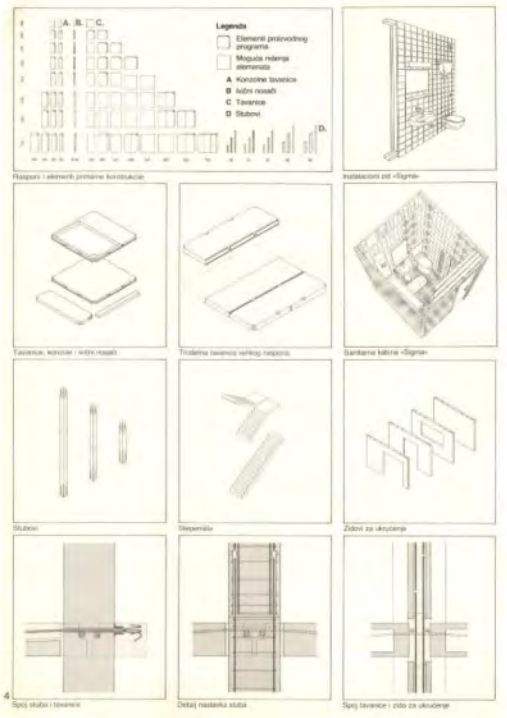

Figure 4. Elements of the IMS Žeželj system. Source: System IMS, 4–5.

4 CONSTRUCTION IN THE SHADOW OF FOREIGN POLICIES

In 1966, the devastating Hurricane Alma hit the islands and mainland of Cuba, causing millions of dollars' worth of damage and 12 deaths. As a part of the international relief effort, Yugoslavia donated an IMS Žeželj system plant with a production capacity of 1500 dwellings per year to help alleviate the housing crisis, to be assembled in Santiago de Cuba. The colorful 18-storey high housing towers built with the IMS Žeželj technology dominate the cityscape to this day. In addition to housing, other typologies were

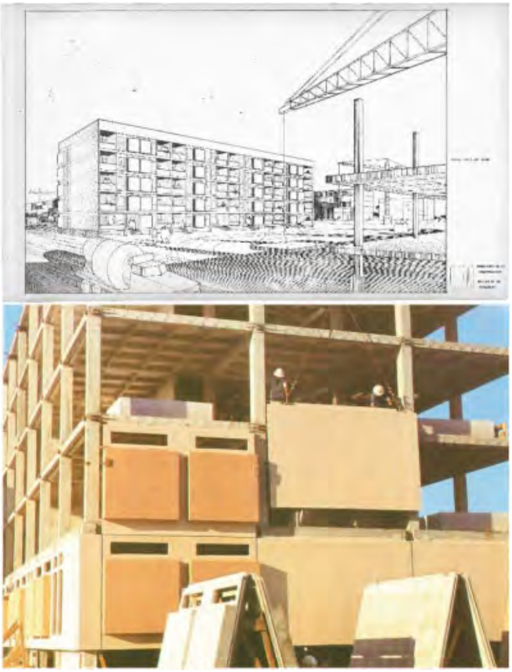

Figure 5. Experimental building of the Cuban Ministry of Construction, location unknown, ca. 1970. Source: Institute IMS archive.

also built. Although diplomatic relations with Cuba had been established from 1951, with the Yugoslav embassy in Mexico also servicing Cuba, all ties were severed in 1958 when the Batista regime refused to issue the Agrément for the Yugoslav ambassador. After the Cuban Revolution, in 1959, the government of Yugoslavia immediately dispatched to Havana the Federal Secretary of Foreign Affairs, the prominent intellectual and revolutionary Konstantin Koca Popovic. Popovic was a surrealist poet who was also a Spanish Civil War and Second World War veteran and revolutionary. His task was to discover who was tasked with establishing diplomatic relations with the new revolutionary government. At first, he was not received warmly because of Yugoslavia's split with the Soviet Union. "The Cubans are very suspicious", Popovic reported back to Belgrade, "they consider us to be revisionists." Although they remained relatively suspicious of Yugoslav self-managed socialism and occasionally raised disputes within the NAM, the Cubans nevertheless accepted the establishment of the Yugoslav embassy and bilateral relations improved over time (AJ, I-5-b/67). By the early 1970s Cuba imported two additional fully equipped IMS Žeželj factories, assembled in San José in Havana and Cienfuegos, thus totaling three *Plantas de Vivienda Yugoslavia*, PVYC, with a combined capacity of 4500 units per year. Knowledge transfer was an integral part of the technology export, and the Cuban Ministry of Construction decided to open another five Outdoor National Factories in Guanajay, Santa Clara, Camagüey, Cárdenas and Bayamo, each with a production capacity of 500 units per year. The total construction capacity of the IMS Žeželj plants in Cuba thus reached 7000 units per year. What made this export especially valuable and successful was the fact that local experts continued experimenting with and improving the system. They developed new methods of joinery, enlarged the spans, remodeled the prestressing geometry, redesigned slabs, and other components, and experimented with the design of other typologies, such as schools and administrative buildings (Marín, Navarro, IMS '87, 253–63).

In an unusual turn of events, the IMS Žeželj system then traveled from Cuba to Angola. On 5 November 1975, the so-called Operation Carlota began in Angola, as Cuba dispatched combat troops to support the fight of the People's Movement for the Liberation of Angola (MPLA) in the Angolan Civil War. Besides the troops, the Cubans also sent one of the IMS Žeželj plants with them, as a gift for the newly established People's Republic of Angola. As the proxy war continued to ravage the former Portuguese colony, the country's officials continued to look for assistance wherever possible, turning to their most loyal allies. Socialist Yugoslavia was among them; the leadership of Yugoslavia had supported the Angolan independence struggle since 1961, when – among other UN members – it was approached by the Workers' Union of Angola (UNTA) and asked to raise the question of Angola and other Portuguese colonies in front of the UN General Assembly (AJ, I-5-b/3-1). In 1976, an official delegation from Angola paid a visit to the Yugoslav Federal Committee for Economic Cooperation with Developing Countries, in order to request structural support in the rebuilding of the country. Upon realizing that in Luanda, the capital of Angola, an IMS Žeželj plant already existed, it was decided by the Committee that structural assistance in construction should be based around this plant and the IMS technology. An urban planning project was developed by the team of the Institute IMS, led by prominent urbanist Živojin Bata Karapešic, for a neighborhood in the north of Luanda, as well as a catalog of typified housing configurations by the prominent architect Branislav Karadžic. Finally, architect and researcher Ivan Petrovic was tasked with developing a project for a construction site for experimentation and training, which consisted of two residential buildings of irregular, complex architecture, with the goal of instructing the local engineers and workforce on how to use the system and the plant. With the war still going on, a small crew of local builders and experts from Yugoslavia constructed two buildings on the site of a former landfill, between the present-day streets of Rua Helder Neto, Rua Pres. Marien Ngouabi and Rua Joaquim Dom C. da Mata in Luanda, relatively distant from the location for which the urban plan had been developed. Paradoxically, the elements were made in one of the older French plants, not the one brought from Cuba. The local Ministry of Construction

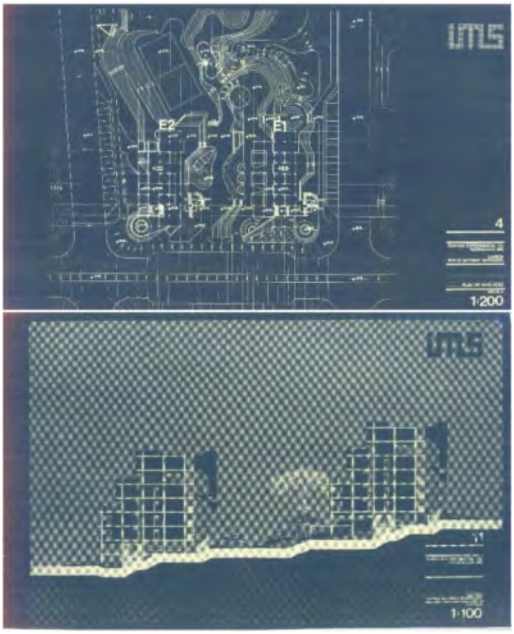

Figure 6. Blueprints of the Lixeira experimental housing, team lead Ivan Petrovic, ca. 1976. Source: personal archive of Dr Ivan Petrovic.

authorized the enterprise Pre-Fabricados UEE to collaborate with the Invest-Import enterprise from Belgrade in order to manage all the necessary steps of the process: design, supervision, import of the equipment, etc. (Koprivica, IMS ’87, 283–8). However, according to the available data, these were the only two buildings built utilizing this technology, and it is not known what happened to the plant in Luanda. Although aware of the buildings, until recently local architects were not aware of the origins of the Lixeira experimental site, and it is still unclear whether production in the gifted IMS Žeželj plant ever started (Jovanovic b, 175–80).

Almost simultaneously with the Angolan events, the Ethiopian Emperor Haile Selassie I was dethroned by the Derg – the Provisional Military Government (later Council) of Ethiopia. The representatives of the Derg had already contacted the Yugoslav government at the beginning of 1975, and in 1976 they met with the representatives of the Federal Secretariat of Foreign Affairs, Secretariat of Defense, Secretary of the Interior, and other officials. Although Ethiopia was never a traditional colony, because of the occupation by Italy, it shared with Yugoslavia common historical adversaries a negative experience of European imperialism. The friendly relations between Ethiopia and Yugoslavia dated back to 1947, when the two countries supported each other in their territorial disputes with neighbors: Ethiopia’s over Eritrea and Yugoslavia’s over Trieste claims. Common membership in the NAM made the connections even stronger. Furthermore, “[…] the revolutionary changes in Ethiopia have contributed to traditional friendship and bilateral cooperation becoming even more important” (AJ, F574, f54) (Figure 6).

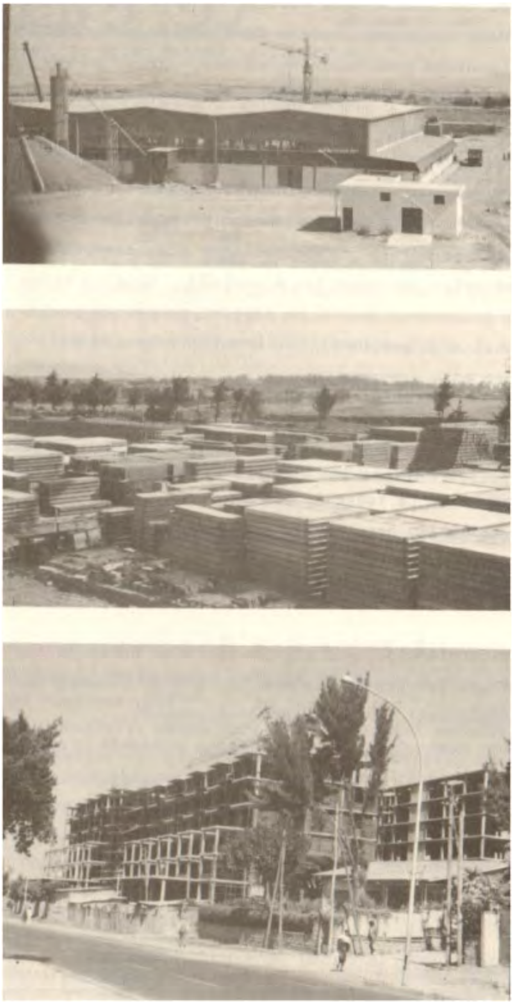

Figure 7. IMS Žeželj plant and the first building “Bole 100 AB” built using the system in Addis Ababa. Source: IMS ’87, 277.

In short, following the Derg coup, nothing changed between the two countries, and economic cooperation continued undisturbed, predominantly in the fields of agriculture, industry, services and tourism. By 1983, the Ethiopian Building Construction Authority (EBCA) decided to address the sluggish housing development by importing the IMS Žeželj system, via the Rudnap enterprise, which had already been present on the Ethiopian market, where it took part in the development of the country’s industrial capacities. The contract was very specific: the plant was supposed to produce 50,000 m^2/year, 45% of which should be components for five-storey housing, 45% for 10-storey housing, and 10% for public buildings. The plant totaling 8566 m^2 in area was built between 1984 and 1986 in the industrial zone of Addis Ababa, which was infrastructurally fully equipped. This was the first plant abroad to be primarily built and supplied with the equipment provided by Yugoslav companies, with the exception of vibration tables imported from West Germany and Sweden, and the concrete mixer built in Italy. In the summer of 1986, an experimental site, “Model II”, was organized in the plant, to train the plant’s local staff and builders for on-site assembly. In February 1987, the assembly of the first building utilizing the IMS Žeželj technology commenced. The “Bole 100 AB” building (Figure 7) was designed by Bulgarian architect Matey Mateev, with structural design by the EBCA civil engineer Asrat, with experts from Yugoslavia supervising the process (Seferovic, Mateev, IMS ’87, 265–82). In the years to come, many buildings of various purposes and scales would be erected using the IMS Žeželj plant around Addis Ababa. However, it seems that the system’s application never reached its full potential and failed to proliferate, as the local scene today continues to rely on traditional construction methods, even though Ethiopian experts established that the IMS Žeželj was up to five times more efficient and less costly than the traditional methods (Mebratu 2019, 39–44, 106–9).

5 CONCLUSIONS

With its origins in the expansion of industrial capitalism, prefabricated construction is closely linked to the dark histories of enslavement and colonization. However, prefabrication also had alternative genealogies rooted in the networks of socialist and postcolonial emancipation, which strove to elevate the masses across the globe out of poverty and dependence. The impact and success of these efforts are yet to be fully evaluated – hopefully, more research will come from the countries which received the technology – but they should also be valorized for the path undertaken and the obstacles that the actors involved strove to overcome. (IMS) Žeželj is one of those agents of alternative modernity, whose story is not only about construction, but also the broader efforts behind it: technological emancipation, locally sourced materials, and labor, fostering the local technical and professional resourcefulness, building self-confidence and assertiveness of the local professional scene and industry. Furthermore, IMS Žeželj technology traveled abroad most often by utilizing the anticolonial networks, established through the Non-Aligned Movement: the plants were either donated or purchased through low-profit deals or favorable loans and covered by the interstate bilateral agreements, while the technology transfer would usually occur through the institute of the UN technical assistance. Every project was treated as a unique learning opportunity, as the IMS Institute kept close contact with the designers and the construction enterprises, often leasing their employees via short-term contracts to conduct the technology transfers where needed, and kept records of the systems’ application. The reality is that all countries that bought or received the IMS Žeželj technology were able to freely experiment with it, to modify and improve it to meet their own needs, to employ the system and its clones for their own purposes, testifying to the emancipatory character of this technology. IMS is worth exploring and further analyzing – even if one might occasionally doubt the sincerity of its creator Žeželj and the Yugoslav government, as even today, decades after the handover, in some instances the technology continues to produce results. After the system’s decades-long international application, regardless of its disappearance from mainstream housing construction, it is evident that its successes and failures correlate strongly with the strength of the governance and the planning efforts behind it, as well as its genuine incompatibility with the neoliberal doctrine dominating the global economy. If the Manning House, was “the technology of colonial expansion”, IMS Žeželj had demonstrated it to be exactly the opposite – the technology of anti-colonial emancipation.

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Thematic session: Construction cultures of the recent past. Building materials and building techniques 1950–2000

History of Construction Cultures – Mascarenhas-Mateus & Paula Pires (eds)

The construction of efficiency: Glazing insulation in France and Belgium since 1945

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ABSTRACT: The growth of Western urban landscapes in the aftermath of World War II brought new standards of com-fort and convenience; one of the emblematic products of this modernization was glazing. Openings became larger, enhancing transparency and bringing abundant light; however, they also led to considerable heat loss. It became imperative that glazing play a part in insulating buildings. This article traces the history of glaz-ing insulation across the second half of the 20th century. Focusing on case studies of residences in France and Belgium and industry archival material, this article analyses the wide variety of glazing products that were developed between 1950 and 1990. Although all of them significantly improved thermal comfort, each conditioned the relationship between indoor and outdoor climates in a different way. In response to increas-ing demands for energy efficiency, sealed insulated glazing ultimately became ubiquitous, bringing about a profound transformation of our relationship with our environment.

1 INTRODUCTION

Glazing is a singular construction element insofar as it must meet a double, *a priori* contradictory, requirement: opening up a room to provide light and transparency while also enclosing it to ensure continuity of the thermal and acoustic insulation with the rest of the building envelope. In the aftermath of the World War II, the glass industry developed a new response to this contradiction; namely, insulating glass units. These units were made of at least two sheets of glass sealed together so as to leave a cavity of dry air, thus radically improving window insulation. They quickly became essential products for modern standards of comfort. Double and triple glazing enabled the construction of fully glass buildings to spread across Europe, all the while meeting increasingly stringent energy policies.

However, while the use of insulating glass units seems unavoidable nowadays to meet thermal regulations, the post-war decades saw the development of many other construction techniques which provided both transparency and insulation, such as double windows, secondary glazing and breathable double glazing. This article focuses on these alternatives and the sociotechnical paths they shaped.

The aim is to understand how the imperative for energy efficiency materialized in glazing throughout the second half of the 20th century and how it has contributed to the transformation of the way we interact with our environment. Drawing on the archives of the glass manufacturer Saint-Gobain and on a review of professional journals, this paper focuses on housing in France and Belgium, two countries at the heart of the European glass industry.

First, the post-war trajectory of insulating glass units is examined, in particular the technical obstacle posed by the sealing, which contributed to uneven growth in its use. Second, the paper looks at alternative techniques which circumvented the need to seal the glass sheets yet still provided substantial insulation. Thirdly, it explores why these alternatives have remained marginal and why the use of double glazing ultimately became widespread, by association privileging a certain way of constructing our relationship with the environment.

Throughout this article, different assembly methods of insulating glazing are discussed. In order to avoid any confusion with contemporary usage, the terms “insulating glass units”, “insulated glazing” and “double or triple glazing” refer exclusively to those with two or more glass sheets separated by a hermetically sealed air cavity. For other types, appropriate adjectives are used to differentiate them.

2 GUARANTEED TIGHTNESS: THE ADVENT OF INSULATED GLAZING

Although the first patent for insulating glass dates back to the 19th century (Stetson 1865), it was only at the end of the 1930s that the glass industry developed a satisfactory technique to hermetically seal the inner cavity, thus solving one of the principal technical barriers of this kind of glazing.

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In 1937, the American company Libbey-Owens-Ford launched the first insulating glass units under the name of Thermopane. They consisted of two panes of glass held apart by a spacer and enclosing a dehydrated air cavity, hermetically sealed by a strip of lead-bonded alloy of copper and aluminium (Barber 2016: 24–5, Leslie 2019). This product was introduced in France in 1947 (R. L. 1947) and in the same year in Belgium by Glaver (Van de Voorde et al. 2015). This company soon developed a new sealing technique which consisted of an aluminium strip with a rectangular cross-section filled with silica gel, which acted as a desiccant for the air in the cavity. They sold the product under the name of Aterphone (Compagnie de Saint-Gobain 1953).

Insulated glazing quickly gained a prominent place in post-war modern architecture, as illustrated by a number of iconic projects that made particularly early use of it. For instance, the 60 flats in the Anjou building were equipped with double-glazed windows. The flats were designed by Marcel Lods and constructed from 1948 to 1949 as part of the reconstruction of Sotteville-lès-Rouen (Anon 1948). In the Cité Radieuse (1947–1952), Le Corbusier used nearly “8,000 square metres of double-glazing”, which was held by “25 kilometres of Lucolène mouldings” (Wogenscky 1949: 5).

However, these buildings were emblematic of an architectural avant-garde that enthusiastically integrated industrial innovation in its designs. In more mainstream residential and commercial buildings in Belgium and France, single glazing remained the norm, even though the new insulating glass units were indisputably superior in terms of performance. For example, Aterphone had a sound reduction index of at least 38 decibels and “a reduction of 45% in heat loss compared to single glazing” (Compagnie de Saint-Gobain 1953). This significant improvement in comfort was a major marketing argument, although the price of insulating glass was four to five times higher than that of single glazing.

A further issue deterring potential customers was the fact that French and Belgian companies only guaranteed their double-glazed units for a maximum of five years. Improving the way the glass sheets were assembled in the glazing unit was necessary to extend this guarantee. The arrival on the market of new materials such as silicone led to the development of more durable joints, prompting Saint-Gobain and Glaver bel to offer a 10-year guarantee from the 1960s onwards (Souviron, in prep., Van de Voorde et al. 2015) (Figure 1).

Around this time, the modernist ideals of transparency and comfort became more widespread, resulting in the use of larger panes of glass. In parallel, central heating systems became common and national governments and industries began to place greater emphasis on insulating buildings (Van de Voorde 2015, Chemillier 1997: 249–50). The first oil crisis prompted the development of the first thermal regulations, which acted as a catalyst for the wider use of insulated glazing. While double glazing was marginal in the 1940s, it was installed in about 10% of French households in 1970 (Chemillier 1997: 185). Simultaneously, the use of insulating glass units in the Belgium-Luxembourg economic union reached 680,000 m^2 per year, and exceeded two million square metres ten years later (Commission of the European Communities 1984: 122).

Polyverbel

de plus en plus utilisé

de plus en plus apprécié

SÉCURITÉ ACCRUE

un profilé intercalaire en acier galvanisé

un profilé U de polyéthylène doublé intérieurement de colle plastique

confirment la supériorité du POLYVERBEL en matière de vitrages isolants.

- Etanchéité
- Risque de casse inexistant
- Planéité Univerbel

1 Feuilles de verre Univerbel
2 Intercalaire en acier galvanisé
3 Silica gel
4 Profilé U de polyéthylène
5 Cadre en acier inoxydable
6 Joint plastique

Univerbel

UNION DES VERRERIES MÉCANIQUES BELGES S. A. - 29, QUAI DE BRABANT - CHARLEROI

CXXVIII

Figure 1. Advertisement for the Polyverbel double glazing (*La Maison* 1959: nº. 6, CXXVIII).

But analysing the history of insulating glass solely by comparing “energy-intensive” single glazing against “efficient” double glazing would be misleading. In fact, while the glass industry was striving to improve the sealing techniques of insulating glass units, other glazing systems were being developed. They proved to be credible alternatives for reducing energy use and suggested other approaches to conceptualizing the specific way insulating windows construct our relationship with the environment.

3 INSULATING WINDOWS WITHOUT INSULATED GLAZING

The growth of the building sector in post-war France and Belgium went hand in hand with the industrial development of new technologies associated with enhancing comfort. But beyond innovations such as insulated glazing, some old techniques were also implemented. This is the case of the double window, which uses two sets of glazed sashes with an air space between them typically between 10 and 20 cm. Double windows had been common in Europe since the

19th century and, in the 1940s, were still one of the most efficient solutions for reducing noise pollution and improving thermal comfort (Anon 1947; Gruzelle 1943).

In post-war reconstruction in France, the double window evolved to meet the increasing industrialization of construction sites. One such example is the detached and semi-detached houses designed by the architect Gauthier in Saint-Dié in 1949 (Figure 2). These houses were designed with wooden window units comprised of two glazed sashes with a shutter made of plywood panels between them, "mainly intended to prevent heat loss during the night" (Muller 1950: 80). These units were pre-fabricated and installed before the walls, which were made from hollow pozzolanic blocks. This double window system helped to meet the ambitious specifications of the Société Nationale des Habitations à Bon Marché (SNHBM) des Hautes-Vosges, which commissioned these houses and expected good thermal performance: "The very high level of insulation required was surpassed because the size of the openings was reduced, and through the use of double panels for both the plain walls, and the door and window glazing" (Muller 1950: 80).

Also working for SNHBM, the architect André Bertrand opted for double windows when he built the "type IV-B" semi-detached houses in a neighbouring area a year later (Bertrand 1950). In the Beaulieu district of Saint-Etienne, the architects Édouard Hur, Jean Farat and Henri Gouyon won the tender to build low-rent housing (Habitations à Loyer Modéré, HLM). Built between 1953 and 1956, their project consisted of 1260 flats with integrated wooden windows incorporating "double glazing by added sash" in the larger openings (Anon 1952).

These three projects reflect the general atmosphere in this post-war period, when the building sector was engaged in a wide range of experiments to improve comfort in European housing. With increasingly noisy cities, reducing noise pollution became of considerable importance, alongside limiting heat loss Isobaie was one of these products (Figure 4). Although it came in many different forms, it was always based on the same principle: a 4 mm or 8 mm glass sheet (sometimes toughened) held in an aluminium frame (Saint-Gobain Vitrage 1976: 145–7). This structure was screwed onto an existing frame (most were made of wood at the time), thus utilizing the pre-existing single glazing. given the costs associated with centrally heated housing. Faced with this challenge, the double window offered significant benefits: it reduced noise nuisance by one third and heat loss by a half, when compared to a single-glazed wooden window (Fossdal 1996). Its performance was even slightly better than that of double glazing, which was still in its early years of development.

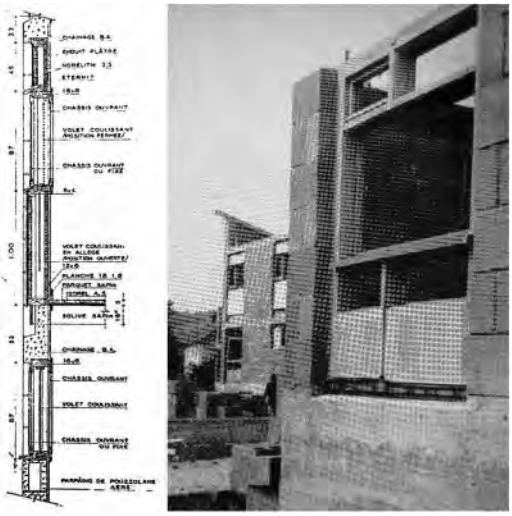


Figure 2. Vertical section and photograph of a wooden window unit integrating two glazed sashes and shutters. Semi-detached houses type IV A (*L'architecture d'aujourd'hui* 1950: n°. 32, 80–1).

This led Saint-Gobain to launch "Duetto" in the early 1970s, an industrialized version of the double window (Figure 3). Unlike double windows, Duetto consisted of a single wooden frame. Two parallel rabbets 40 mm apart held two toughened glass panes, both of which were removable for easy cleaning and repair through an operating and locking system (Saint-Gobain Vitrage 1976: 136–7). The Duetto window achieved a sound reduction index for traffic noise of some 37 dB (A) and a thermal conductivity of 2.8 W/m^2· K, This last value was equivalent to that of a wooden window assembled with Polyglass, which was the standard double glazing produced by Saint-Gobain at that time.

In 1975, Saint-Gobain extended its range of insulating glass with Isobaie, a series of secondary glazing for renovation projects (Saint-Gobain Vitrage 1975). In the meantime, the first oil crisis prompted the French government to subsidize retrofitting via the Agence Nationale pour l'Amélioration de l'Habitat (National Agency for Housing Improvement – ANAH). The aim was to accelerate the insulation of the French building stock, creating an attractive context for the construction industry, especially for Saint-Gobain, which found a flourishing market for its insulation products.

The addition of a secondary glazing improved thermal resistance, using the same logic as that of a double window: an insulating air cavity was created between the two glass sheets. However, unlike insulated glazing, the unit was not sealed. Such upgraded windows had a maximum thermal conductivity value of 3 W/m^2· K, but this was reduced to 2.3 W/m^2· K from 1986 onwards, when Saint-Gobain developed Eko, a low-emissivity glass with a metallic salt coating that minimized heat loss (Saint-Gobain Vitrage 1986: 55, Saint-Gobain Vitrage 1988: 226–9).

The frame and glazing of the Isobaie T32 had to be assembled by a craftsman but could then be fixed onto the existing window by the user. Self-assembly kits

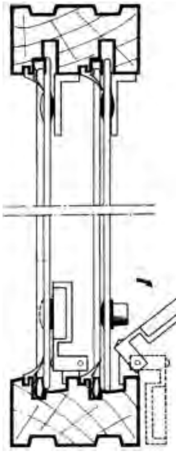


Figure 3. The Duetto double wall window with two toughened glass sheets and their operating and locking systems (Saint-Gobain Vitrage 1976: 137).

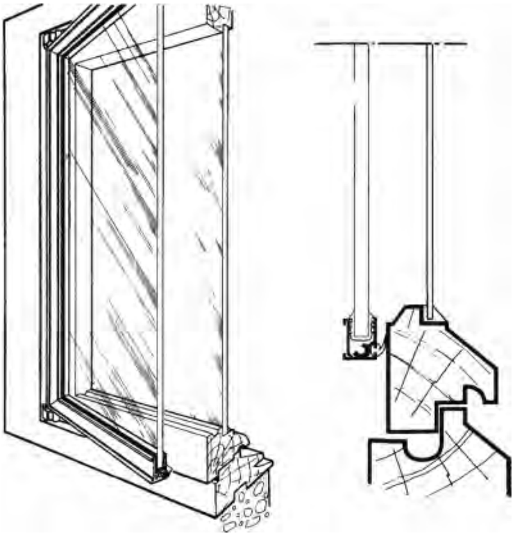


Figure 4. The Isobaie T32, a secondary glazing system developed by Saint-Gobain from 1975, here installed on an existing wooden window (Saint-Gobain Vitrage 1976: 137).

(the T28), were also available; these could "be installed in a few minutes by anybody with basic handiwork skills" (Saint-Gobain Vitrage 1975: 6) (Figure 4).

This was a great advantage in the economic context following the oil crisis, particularly given the fact that it avoided the need to replace existing frames, which often had rabbets sized for single glazing and were therefore too thin to allow the installation of insulating glass units. Nevertheless, the production of Duetto and Isobaie was halted at the end of the 1980s. Instead, Saint-Gobain focused on double glazing and highlighted a new range of glass products for retrofitting. The latter was called "R Renovation" and consisted of double glazing pre-assembled in an aluminium frame (later PVC), which could be fixed directly to existing wooden windows. From this time on, insulated glazing, and in particular double glazing was almost the sole means of reducing heat loss in windows.

4 GLAZING BEYOND INSULATION EFFICIENCY

Stricter thermal regulations were published in France in 1982 (together with a *Label Haute Isolation*), and in Wallonia in 1985, making sealed units of insulating glass almost unavoidable in all kinds of buildings, particularly given that they were cheaper and easier to install than a double window. The use of secondary glazing had engendered the reuse of panes of glass and frames, particularly in renovation projects, but the growing popularity of cheap plastic frames and the continuing decline in the price of glass now favoured the outright replacement of windows. New double-glazed PVC windows also had the advantage of being considerably easier to maintain, a point regularly stressed by advertisements. The hermetic and dust-tight seal in double glazing meant that only two glass faces needed cleaning, in contrast to four faces for double windows and secondary glazing.

But while this technical solution was undoubtedly more convenient, it did not come without drawbacks: maintenance was unnecessary, but it especially transpired to be almost impossible (Souviron, in prep.). Unlike wooden frames, plastic window frames cannot be sanded, painted, varnished, carved, glued or screwed. Wood is demanding in terms of maintenance; it has to be repainted every 5 to 10 years, and the glazing putty carefully monitored. But these are precisely the factors that make it a durable product. Indeed, a wooden window can last for more than 50 years, and ease of repair has enabled many frames to become centenarians. In contrast, a plastic window has an average lifespan of around 20 years and usually ends up in landfill (Souviron et al. 2019).

In terms of insulating glass units, decades of research have not led to the development of a seal that is eternally resistant to fatigue and weather conditions. Nowadays, the average lifespan is generally between 25 and 30 years, a period beyond which the seal may no longer be watertight. In this case, condensation enters the insulating cavity and reduces both thermal resistance and transparency. Cleaning and repair are almost impossible due to the sealed assembly of the two panes, which prevents their separation and thus access to the interior cavity. The replacement of units then becomes necessary, being also favoured by government energy policies and by the glass industry itself, as both promote the use of new and more efficient products (for example, low-emissivity glass, argon insulation, self-cleaning coatings, ultra-clear glass, etc.). The history of glazing efficiency cannot be disassociated from architectural obsolescence (Abramson 2016), which has led to the disposal of 1.5 million tonnes of glass per year in European landfill sites (Souviron 2020).

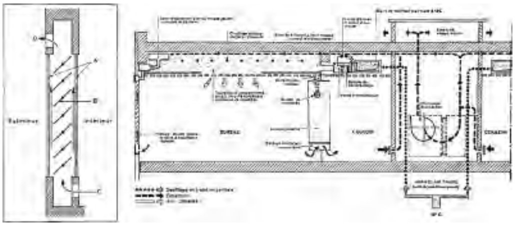


Figure 5. A ventilated double glazing unit integrating a blind between its two glass panes (left), and a section of an office with ventilated double glazing installed as part of a mechanical air conditioning system (right) (Cimur 1968: 35–36).

This ecological challenge was identified as early as the 1970s. Concerns around the obsolescence of insulating glass units led to the design of repairable insulating glass units. This was the case with the Duetto window discussed above, which had a system allowing users to unlock, separate and maintain each glass sheet individually. This was also the case with the "breathable" glazing (*vitrage respirant*), developed in the 1980s by the French Scientific and Technical Centre for Building (CSTB). The latter conducted research to "find a technique for repairing standard insulating glazing that became misty after 20 to 30 years".

It finally developed a system which consisted of "making the air gap in insulating glazing communicate with the outside, so that the performance of the glazing [could] be restored to initial values" (CSTB 2008). This research echoed experiments on ventilated double glazing in the 1960s, which also aimed to let the air flow freely inside the insulating cavity (Cimur 1968). However, its use was limited to climate-controlled offices, where the air circulating between the glass panes was mechanically controlled and used as an integral part of an air-conditioning system (Figure 5).

In the residential sector, a number of patents were issued throughout the 1980s for technologies that reinterpreted this principle of "breathable" glazing (Figure 6). One of them was aimed at both renovation and new constructions and brought a "simple and inexpensive" improvement in the technique of secondary glazing (Mohring & Denance 1986). These often resulted in an increased risk of condensation, meaning that the insulating cavity needed frequent cleaning. The solution was to free the air inside this cavity through small openings, thus equilibrating the internal humidity rate with the outdoor rate. This technology was developed three years later in a patent for a "dynamically insulated window", where "each glazed element [could] be opened like a box" (Paziaud 1989).

These inventions improved the thermal resistance of windows without the need for sealed glazing. This allowed users or craftsmen to take out each glass pane by simply removing the glazing putty and bead. In contrast to sealed insulating glass units, the simple fact that it was possible to repair these units changed and enhanced the relationship between windows and their users. Devaluation was no longer inevitable, nor a *de facto* end-of-life in landfill; units could be restored and even upgraded. Maintenance empowered both the user and the craftsman by conferring upon them a certain level of technical autonomy (Granstedt 1980).

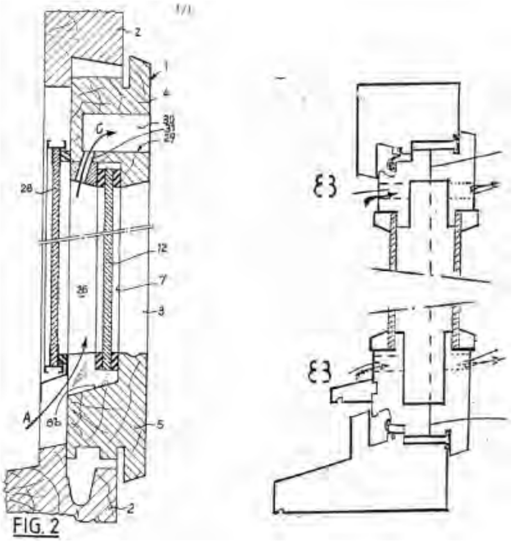
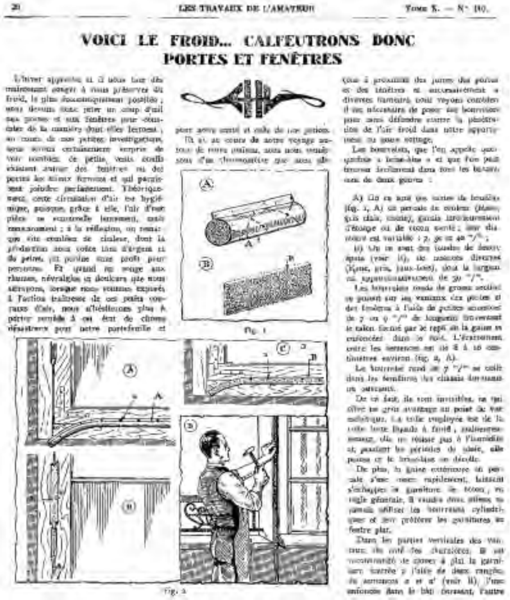


Figure 6. (Left); A secondary glazing pane mounted on the outside of a single-glazed wooden window, which includes holes for the circulation of air from the outside to the inside. (Right); A window frame with two openable single glazed sashes, with a ventilated air cavity in between. (Mohring & Denance 1986; Paziaud 1989).

Until the middle of the 20th century, this autonomy was encouraged through the many do-it-yourself magazines which provided advice on how to maintain and repair glass panes and wooden frames (Souviron, in prep.). Secondary glazing followed a similar sociotechnical scheme, particularly in its kit version as sold by Saint-Gobain from the 1980s onwards. Greater comfort was provided, but not at the expense of the existing construction; secondary glazing in fact took advantage of pre-existing elements and sought to capitalize on their potential economic and technical benefits (Fossdal 1996; Pickles 2012). The design of different types of glazing throughout the second half of the 20th century circumscribed the possible life cycles of a window and the degree of control exerted by users. While in some circumstances this was a deliberate process, in many it was the involuntary consequence of a search for efficiency. Accordingly, the design of an insulating glass unit has not only defined a new relationship with windows, but has also conditioned the possible modes of interaction with the environment. As previously discussed, the changes in this interaction had been determined by the fact that it was increasingly difficult to repair windows. This was due to the sealed assembly which constrained users to interaction characterized by heteronomy, then abandonment and finally landfill.

Beyond this issue of waste and its socio-ecological challenges, considering other forms of interaction with



LES TRAVAUX DE L'AMATEUR

VOICI LE FROID... CALFEUTRONS DONC PORTES ET FENÊTRES

Figure 7. Until the middle of the 20th century, during the winter, many DIY magazines gave advice on how to improve the insulation of dwellings, including the best techniques for draughtproofing doors and windows. (Anon. 1930: 26).

BETTER YOUR LIVING in a new home with *Thermopane*® between you and the weather

You'll be happier in a new home! Today's new homes are better planned for family living. And better built! Builders are using advanced building materials, like *Thermopane* insulating glass! It keeps you snug in winter, comfortable in summer.

Builders know that without windows of *Thermopane* a house is only *partially* insulated. It's colder in winter—harder to heat; hotter in summer—harder to keep cool. Costlier to keep comfortable all year 'round. *Thermopane*'s two panes of glass, with dry air between, cut down fogging and frosting . . . protect you from drafts . . . increase your living space because you're comfortable close to windows. You can forget about storm windows!

This weekend, why not visit the model homes on display in your community? And write for your copy of the beautifully illustrated booklet describing *Thermopane* insulating glass and what it does for you. Dept. 6108, Libbey·Owens·Ford Glass Company, 608 Madison Avenue, Toledo 3, Ohio.

Figure 8. Advertisement for the Thermopane manufactured by the American company LOF. The transparency and size of this double glazing literally makes the boundary between outside and inside disappear, accentuating the contrast between the “natural” outdoor climate and the fossil-fueled indoor climate (Better Homes & Gardens 1958: Vol. 36, No. 10).

the environment is important, in particular how people behave in response to different weather conditions. Until the second half of the 20th century, this was governed principally by the rhythm of the seasons: as winter approached, the only means of reducing heat loss in simple-glazed wooden windows were shutters, curtains and draught-proofing techniques (Figure 7).

The double window led to major improvements in comfort, also resulting in changes in behaviour. In winter, insulation was around 2.5 $W/m^2 \cdot K$, and as such, already fairly satisfactory; as with single glazing, it could also be increased by using curtains and shutters, such as in the houses in Saint-Dié. In the summer, opening one of the two glazed sashes turned the double window into single glazing, thereby increasing the heat loss to a value of about 5 $W/m^2 \cdot K$. In this way, the heat could dissipate faster, especially at night, while still maintaining the security provided by a closed window. Therefore, this system offered thermal resistance that was variable according to the time of day and the season – something that secondary glazing could also provide when the unit could be opened.

In contrast, although insulated glazing improved indoor comfort, it nonetheless reduced the capacity of a window to adapt to technical challenges (for example, condensation) and meteorological variations. Larger glazed surfaces contributed to the dissemination of modern ideas around convenience, while a new “sociotechnical landscape” (Rip & Kemp 1998) was taking shape around the imperatives of energy efficiency. The steady strengthening of energy regulations fostered extensive research and development into indoor climate control and consumers in Western Europe invested enthusiastically, thus enabling their way of life to become increasingly disconnected from seasonal patterns. Insulated glazing, and particularly double glazing, played an emblematic yet contradictory function in this evolution: on the one hand, they have embodied a modern aesthetic of transparency, “dissolving the wall as an architectural element” and thus blurring the boundary between inside and outside (Forty 2004: 286); on the other hand, their increasing tightness and thermal resistance have made it an impermeable boundary between the indoor and outdoor climates (Figure 8).

Finally, the history of glazing insulation reveals the gradual retreat of the Western world from the outdoor environment, in search of modern comfort. Houses have not only become better insulated, but also easier to maintain and are often air-conditioned. Double glazing is only about 1 cm thick and manages the interface between two climates, thus avoiding the need for users to pay close attention to the weather, except when setting the thermostat. When seen through large insulated bay windows, the weather becomes an almost abstract notion, perceived solely through our sense of sight; it contributes to the definition of an interior atmosphere that is all the more appreciated given that the contrast between the two climates is so striking. Thus, by rejecting inconvenient aspects of the outside environment, insulated glazing acts as a filter. This filter has been improved since the 1950s with the constant introduction of new functions (Lloyd Thomas 2012). One such example is self-cleaning glass, developed in the 1990s and first distributed by Saint-Gobain in 2001 under the brand name Aquaclean – then renamed Bioclean (Chartier et al. 1996; Saint-Gobain Glass 2001). This glass chemically removes the physical traces left by external elements such as rain, dust and pollution, thus freeing the homeowner from the ultimate inconvenience of glazing: the need to clean the windows.

5 CONCLUSION

In the post-war decades in Western Europe, considerable priority was given to the construction of dwellings, thus contributing to tremendous economic and industrial growth. This led to a significant improvement in comfort and a certain modernization of the Western lifestyle, and insulated glazing became an important protagonist in the process. Large panes of glass reflected the emergence of new urban and suburban conditions. They no longer merely provided light, but began to act as an insulating material thanks to its thin cavity of dry air. Nonetheless, the development of insulating glass has not been linear and, for decades, the glass industry invested in research on new techniques and materials to improve the durability of the hermetic sealing. Faced with this technical challenge, companies developed alternative systems which also used two glass sheets in order to create an insulating air cavity: double windows and secondary glazing. These glazing types were efficient and functional but remained marginal while double glazing was gradually becoming the almost exclusive means of insulating windows.

Insulated glazing was easier to use than unsealed double-walled windows and has been continuously enhanced in order to meet the imperative of energy efficiency that has characterized the environmental policies since the middle of the 20th century. These policies favoured the implementation of ever more efficient technologies for indoor climate conditioning, despite the fact that they reinforced a certain distancing between man and the natural environment. Drawing on Shove's research, the history of insulating glass finds its place in the history of these energy-efficient technologies that have been "implicated in the construction and maintenance of particular forms of (environmentally unsustainable) 'normality"' (Shove 2003b: 202). "There is, in addition, further ambiguity about the natural or artificial status of an indoor climate that is so completely cut off from the weather outside. Are we to think of ourselves as part of nature or as safely protected from it? There is much less doubt that standard conditions of comfort have been naturalized in the sense that they are now simply taken for granted" (Shove 2003a: 41).

Beyond these questions around the construction of indoor climates, the environmental impact of insulated glazing is also a direct result of its limited shelf-life. The assembly structure of double and triple glazing has guaranteed high performance in terms of energy efficiency but has also made repairing and recycling almost impossible, and has resulted in massive deposits in landfill. In contrast, double windows were easier to repair, secondary glazing even more so, and were designed to preserve and upgrade existing glazing and frames.

At a time when European and national policies aim to accelerate the rate of energy retrofitting, this history underlines the importance of taking into consideration the long-term maintenance of building stock, including its construction elements. A large proportion of windows in France and Belgium are still single-glazed. Indeed, almost half of French homes were still using single glazing in 1995 (Anon 1996), a figure that had reduced to around 40% by 2010 (Pouget 2017). In Wallonia one estimate puts the number of dwellings with simple glazing at 20% (Hauglustaine & Monfils 2009). These buildings are the main targets of energy retrofitting policies today.

Abramson asks a key question: "Capitalism, which sired obsolescence a century ago, today profits equally from sustainability's technophilia. And the question is begged, what happens to today's green building when future innovations render its performance substandard?" (Abramson 2016: 294). One response might come from recent initiatives promoting the repair and restoration of windows. These initiatives resurrect the design of detachable glazing (DeBrincat & Babic 2019) and reconsider double windows and secondary glazing. This is perhaps at the expense of "energy efficiency" but nonetheless pays greater attention to the social usage and environmental histories of our technical objects (Bertrand 2008; Detremmerie et al. 2012).

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Stopray window panes: Use and restoration in various Brussels buildings

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ABSTRACT: In 1961, two giant Belgian glass manufacturers operating globally merged to create “Glaverbel”. The post-war period was marked by new technological challenges. Therefore, in addition to the production of its “basic products”, Glaverbel concentrated its efforts on insulating glass units, thin-film glass, heated glass, enamelled glass, diffusing glass, solar-reflective glass, etc. It is in this context that Glaverbel launched the production of a new reflective glass. By applying a very thin layer of metal or metal oxide to one side of the glass wall, the glass reflects infrared rays. It is this technique which Glaverbel used for its “Stopray” brand. Many buildings with Stopray lightweight façades were constructed in Brussels in the years 1950–2000. This article will present the origins of Stopray glass, its inclusion in the post-war Brussels architectural context, and will focus on its use in various buildings, as well as current restoration issues.

1 INTRODUCTION

1.1 *The creation of Glaverbel*

Throughout history, Belgium has always been an important glass manufacturer. The first Belgian glass factories were founded in the middle of the 19th century. At the beginning of the 20th century, calls for a modernized and mechanized industry, along with the difficult economic climate, led to a reorganization of the sector. A series of important mergers in the early 1930s engendered the creation of three main companies: Univerbel, Glaver and Glaceries de la Sambre. Univerbel or the “Union of Belgian Mechanical Glass Works” was the result of the union of 14 small glass factories in Belgium. The company, founded in 1930, had its headquarters in Charleroi during the post-war period with factories in Zeebrugge, Gilly and Lodelinsart. Glaver (*Société Glaces et Verres*) also emerged in 1931 from the merger of several companies. The company had four factories in Belgium: in Mol, Houdeng, Roux and Moustier. Both Univerbel and Glaver were deemed to be powerful groups, and operated in parallel, competing for almost 30 years. They were in fact complementary: together they produced all forms of flat glass, polished and drawn vertically or horizontally, printed, cast, white and coloured glass, as well as double glazing. In the post-war period, in the 1960s, a second major reorganization of the glass industry was necessary. As a result, Glaver and Univerbel merged to form Glaverbel in February 1961. The newly created company produced a complete range of glass products for the building industry, including drawn glass, polished glass, cast glass, enamelled glass, solar glass, and insulating glass. Prior to the merger, both Glaver and Univerbel produced most types of glass (Delaet & Poty 1986, 225). As a result, during the reorganization, choices had to be made to make up the new product range.

1.2 *The emergence of Stopray*

Between 1945 and 1960, there was a steady increase in the use of glass products in construction. Builders were eager to increase comfort inside buildings, striving for thermal and acoustic insulation and limitation of sunlight through the use of special glass. In the 1950s, the first research on solar control was conducted (NAB 2, Glaverbel archives, 6).

In 1959, S.A. Glaces et Verres (Glaver), whose head office was located at Number 4 Chaussée de Charleroi in Brussels, became interested in reflective glass. Correspondence between two Glaver employees mentions the use of a lacquer called “SUN X”, marketed by the company AMERICAN SUN X OF BELGIUM. The author of the letter identified this product on the windows of three shops located at 66–70 and 76 Avenue Louise respectively. He also mentioned the possibility of applying this product in Thermopane insulating glass. Later, in 1960, discussions were held with the American firm “Sun Control”, mentioning a protective varnish called “Sun Control”. Green Sun Control would prevent infrared rays, which cause heat, from entering, and would therefore be especially valuable during the summer. Another advantage of Sun

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Control was that the varnish retains 97% of ultraviolet rays and therefore provides very good protection against the fading of fabrics and other materials by ultraviolet rays. Sun Control "crystal" is colourless, retaining 97% of ultra-violet rays, but does not protect against heat from infrared rays (NAB 2, Glaverbel archives, 6).

Univerbel kept improving the surface of its products with the clear aim to make drawn window glass the direct "competitor" of polished glass. It is in this context that the company developed new products such as "Stopray" anti-reflective lenses and semi-reflective lenses (Delaet & Poty 1986, 229). The first report on Stopray is dated 22 August 1960 and the product was marketed in February 1961 (NAB 2, Glaverbel archives, 6). Although Univerbel was the first to develop "Stopray", this glass had to be mounted in double glazing, and for this purpose, the "thermopane" product developed by Glaver was selected for the melting process. Stopray is therefore a clever blend of Univerbel and Glaver know-how!

1.3 *An untapped resource*

Stopray was mainly used in office buildings. There are few records of this type of building in Brussels. The writing of this article began with the review of advertising brochures at the *Centre International pour la Ville, l'Architecture et le Paysage* (CIVA) in Brussels, where some documents relating to building materials are available. However, the archives of this company are kept in the State archives in Belgium, more precisely in the AGR (*Archives Générales du Royaume* 2), Joseph Cuvelier deposit. This collection had not been analyzed before. Within the latter, I unpacked 30 storage boxes, using the contents of eight of them to write this text. Since written resources are scarce and difficult to access, I conducted a number of interviews: various employees of Glaverbel, now AGC Glass Europe (Vincent Lieffrig, Daniel Decroupet, Bhadresh Parbhoo); Renaud Jacquet, who was in charge of restoring the façade of the CBR building for the Louis De Waele company; Francis Metzger, the architect in charge of restoring the former head office of the Royale Belge in Watremael Boistfort; and Hugo Massire, a specialist on the architect Pierre Dufau.

The Glaverbel archive collection consists of 240 metres of unclassified archives containing the archives of Mécaniver and Glaver prior to the creation of Glaverbel. Univerbel's archives prior to the merger are virtually non-existent. The deposit slip, which is very sketchy, lists two bags of archives. With the exception of the centralising journal, all attempts to locate them have been unsuccessful.

Since 1976, the State archivists have been negotiating with Glaverbel's management to obtain payment for their documents, which no longer have any administrative use but are of undeniable historical interest. In 1982, unfortunately, the management of Glaverbel, despite repeated contact with the State archives, decided to sell its archives at paper prices to the Formisano company. After being alerted, AGR archivists could only note that a container full of archives had already been destroyed. In June 1982, Glaverbel's archives, which had been saved from destruction, were deposited in the State archives. They are therefore still the property of Glaverbel's successors in title, but the IGAs are responsible for their preservation. The collection has been transferred to AGR, Rue de Ruysbroeck 2-12 in Brussels. In 2002, the collection was packed up, given a serial number (61) to identify it among the kilometres of archives, and transferred to the new auxiliary depository of the AGR: *Archives Générales du Royaume* 2, Joseph Cuvelier depository, opened to the public in 2010 (Caroline Six 16/10/20).

1.4 *The properties of Stopray*

Stopray has excellent light transmission for a given solar factor. Indeed, the precious metals used in Stopray coatings have the effect, on the one hand, of allowing a maximum amount of light to pass through so as to maintain a high level of natural lighting and, on the other hand, of considerably reducing the intensity of infrared solar radiation, which is responsible for overheating. Stopray has high energy transmission levels, which reduces the heat transmitted by the sun's rays by up to 13%. Its action largely eliminates the discomfort caused by direct sunlight. It therefore contributes to a considerable reduction in the costs of installing and operating air conditioning. In addition to its solar protection performance, it also has insulating qualities. The metal layer on Stopray has low emissivity properties: it reflects up to 97% of indoor ambient radiation, allowing the thermal insulation coefficient (U value) to drop to $1.4\,\mathrm{W/m^2K}$. As a result, in cold weather, there is less exchange between the cold outdoor climate and the indoor environment, making it easier to maintain a comfortable temperature. (Advertisement for Stopray insulating glass published by Glaverbel. Coll. CIVA, Brussels).

2 THE PRODUCTION OF STOPRAY

Stopray was originally made from a sheet of drawn window glass or polished glass, one side of which was covered with a thin coating of metal or metal oxide. Very quickly, and still today, it is applied to float glass. Stopray glass can then be assembled in Thermopane double glazing (Van de Voorde et al. 2015, 180).

2.1 *The place where magic happens*

Stopray activities were initially carried out in the former glass factories of Dampremy (Delaet & Poty 1986). After the merger, Stopray was produced by Glaverbel s.a., in the division of La Paix-Univer located in Lodelinsart, in the Rue du Chemin Vert. This is where the central cashier's office and the special products factory were located (NAB 2, Glaverbel archives, 19). Stopray is still produced in Lodelinsart. Of course, new production lines have been installed. In addition, glass melting is no longer carried out at this location. The glass for the Stopray coatings is produced at factories in Moustiers near Namur in Belgium or in Boussois in France (Decroupet 14/12/20).

2.2 *A solar control glass*

To control the effects of the sun, there are two types of glass in the construction industry. So-called "coated" glasses are the most frequently used. These have the property of reflecting some of the incidental solar energy. To do this, there are two types of coatings: pyrolytic coatings based on metal oxides deposited on clear or coloured glass on the glass production line and vacuum coatings based on metal oxides or metals. As these layers oxidize when in contact with air, they must always be placed inside a double-glazing unit, with the glass on the outside (facing the cavity). It is due to this last method that Stopray is obtained (AGC Glass Europe 2018).

There are many Stopray Gold references, such as 20/13, 38/28 and 40/27, which were used extensively in office buildings in Brussels. The numbers after the colour quantify the light transmission and solar factor. Therefore, within Stopray Gold "40/27", "40" refers to light transmission, while "27" quantifies the solar factor, which is the total amount of energy that enters the building. Dividing 40 by 27 results in a factor of 1.5. This means that a selectivity of 1.5 is obtained. These performances are made possible by using reflective layers comprising metals. In the case of pyrolytic layers, manufactured directly on the glass production line and where oxides are used, the selectivity is generally between 0.7 and 1.1, therefore there is almost no selectivity (i.e. similar performance in the near infrared compared to the visible). Lenses with pyrolytic coatings therefore have similar aesthetics to those with vacuum coatings, but with lower performance.

2.3 *Stopray a precious material*

To produce Stopray coating, a glass sheet is placed in a chamber with very little residual pressure. An electrical discharge is then produced between two electrodes at a high potential difference. The sputtering process is the result of the bombardment of an electrode (cathode) by ions. This bombardment causes atoms to be ejected from the cathode material, which can condense on an opposing surface (glass).

In the 1960s, the first vacuum deposition equipment appeared, but with poor vacuum quality. This accounts for gold being used at first. Gold is a very inert precious material (it does not react with anything) and made it possible to work with less efficient tanks (Decroupet 14/12/20). In 1973, the solution adopted industrially by Glaverbel for the vacuum deposition of thin layers, is that of cathodic sputtering with the possibility of evaporation under electron bombardment. The main advantage is the ease with which a uniform deposit can be obtained over large areas (3 × 4 m). The rectilinear shape of "the cathode" or "the cathodes", combined with the regular translation of the glass to be treated in front of it, favours control of the regularity parameters. In contrast, the range of materials that can be deposited is reduced if the electrodes are supplied with a DC or low frequency (50 Hz) potential. Except in the case of some precious metals, the speed of film formation on the substrate is low (NAB 2, Glaverbel archives, 14). Since the mid-1980s, even greater lines of vacuum deposition layers have appeared. These more efficient machines have made it possible to work with more reactive materials such as copper or silver, which also have good reflective properties, but which would previously have been damaged by residual pollutants in the atmosphere. In addition, cathodic sputtering has progressed towards a method assisted by a magnetic field (magnetron sputtering). Since then, the ability to produce the tightest, flattest tanks possible has been greatly improved, and we have seen the evolution of pumping systems that evacuate the area of solid tanks.

The first Stopray shade that was marketed was gold. In 1968, by making variations in the stacking of gold (Au) and Bismuth oxide (Bi2O3) layers, Glaverbel developed Stopray in crimson shades (NAB 2, Glaverbel archives, 26). Using a similar process, again with gold, the company produced a grey-blue Stopray. Over the years, the company tried to manufacture coatings with a multitude of metals (e.g. Zinc, Tin, Titanium). However, the material that caught the company's attention was silver (Ag). In spite of its efforts and numerous explorations, it was only in 1988 that the first production line for silver (Ag) based coatings was installed at Lodelinsart. This was possible because of the improvement of the machines and production line, which made it possible to equip them with the right reflector. Since then, and especially since 1995, silver-based coatings have become much more coveted than gold-based coatings (Decroupet 14/12/20).

2.4 *All that glitters is not gold*

The colour of Stopray is essentially generated by the reflective material and the stacking of layers, i.e. the interference system around the reflective layer. Throughout its existence, Stopray has been available in a wide range of neutral colours with different levels of light and energy performance, including in Brussels: silver (GLAVERBEL headquarters, 1967, by Renaat Braem, Pierre Guillissen, André Jacqmain and Victor Mulpas, chaussée de la Hulpe 166); neutral (CRYSTAL office and residential building, 1992, Avenue Michel-Ange 82–86 and Avenue de Cortenberg 60–64, by the architectural firm Samyn et associés); bronze

(DE LIGNE building, 1971, Rue de la Banque in Brussels, by M. Lambrichs & Partners, R. Delfosse); green, grey, blue …

3 INTERNATIONAL COMPETITORS AT THE TIME

3.1 *In Europe*

A list dated 15 October 1973 (NAB 2, Glaverbel archives, 13) lists the products competing with metal-coated glass in double glazing, among them: Infrastop produced by Flachglas AG, a German company whose range includes Infrastop Gold 40/26 and 30/23; in the same country, VVB Bauglas in Dresden, which developed a product called Theraflex as of 1970; Soltran produced by Boussois in France in the 30/19 and 40/30 gold tint; Insulight Gold generated by Pilkinton, a British company; … (Centre d'assistance technique et de documentation 1981).

3.2 *In the United States*

The report of a trip to the USA between 2–4 April 1968 (NAB 2, Glaverbel archives, 13) outlines that a company called Kinney glazed some buildings, mainly in grey metallic. The offices of the company, located in Philadelphia, were then made in golden Kinney. According to the author of the report, the coating seemed quite suitable, but the support used (drawn glass) was of insufficient quality, which practically deprived this realization of its character of reference. At that time, gilding was not very widespread in the USA. The conclusion of this document was that the US market for coated glass was in its infancy at that time. However, great architectural outputs were emerging which made use of tens of thousands of m^2 of glass, and this movement was likely to be irreversible. Other American glass companies include the Libbey-Owens-Ford Company (LOF) and Pittsburgh Plate Glass (PPG). LOF, which was founded in 1973, mainly produced non-metallic coated single panes and absorbent glass (NAB 2, Glaverbel archives, 13), meaning it did not really compete with the Stopray product. PPG, in contrast, had developed a glass called Solarban as early as 1964. But it was not until 1983, 19 years after the launch of this heat-reflecting product, that PPG launched its first glass manufactured using the vacuum deposition process.

4 THE EVOLUTION OF STOPRAY GOLD

4.1 *From Glaverbel to AGC*

In 1972, the French group BSN (Boussois-Souchon-Neuvesel) took control of Glaverbel and integrated it into its flat glass branch. In 1981, BSN separated from its flat glass branch and Glaverbel was acquired by the Japanese group Asahi Glass Company (AGC). In 2002, AGC took over the entire Glaverbel group. In 2007, AGC adopted a single name for all its companies around the world: Glaverbel became AGC Flat Glass Europe, and in 2010, AGC Glass Europe (De Coninck & Samyn 2014).

4.2 *The evolution of Stopay Gold*

In 1968, Glaverbel gave Stopray a 10-year guarantee (NAB 2, Glaverbel archives, 26). In 1996, plans were made to discontinue the manufacture of gold-based coatings. AGC employees therefore set about trying to reproduce a golden appearance with silver-based coatings. The product was developed but never launched. Customers at the time, mainly from the Middle East, Hong Kong, and Singapore, wishing to purchase Stopray Gold, required a document certifying the use of gold in the production of the glass. Stopray Gold was then a prestigious product! Around the year 2000, production of Stopray with gold-based coatings was terminated, except for a few replacement glazings produced on the Boussois line, taken over by Glaverbel in 1998 (Decroupet 14/12/20). Today, having reached the end of its life, this material is sometimes still in place and presents numerous pathologies.

4.3 *The new generation of Stopray*

In 2016, AGC developed a new technology: the company was able to create customised Stopray glass using the "coat on demand" process. A prototype could be produced after one day of development. Technical specifications and optical properties could thus be defined individually. This service was enabled by virtual prototyping software that is capable of creating an accurate representation of the coated glass in its environment and under different climatic conditions, taking into account the physical characteristics of the glazing. It is possible to refine light transmission, light reflection and colour (AGC Glass Europe 2019).

5 CURRENT RESTORATION ISSUES

5.1 *Stopray has an expiry date*

Reports concerning this type of façade describe three main types of problems: cracked, fogged and oxidised glazing. Indeed, over time and for various reasons, some glazing may have broken. The age of the material and the stagnation of water in the lower joints may cause a loss of watertightness that causes the glass to fog up. The presence of condensation in the air space also creates an aesthetic problem and a loss of transparency in the glazing. Finally, these factors have at times led to oxidation of the inner metal layer, causing a loss of protection against sunlight (Chapelle 2013; Chapelle 2016).

Figure 1. Advertising brochure for Stopray published by Glaverbel, illustrated by the façade of the CBR building in Watermael-Boitsfort. Coll. CIVA, Brussels.

5.2 *CBR: A building where every reflection has a story*

At the end of the 1960s, the activities of Cimenteries CBR nv (formerly known as Cimenteries et Briqueteries Réunies) expanded. The development of various departments and the regular increase in the workforce required the construction of a new building in Watermael-Boitsfort. The architects Constantin Brodzki and Marcel Lambrichs were entrusted with the construction of this building between 1968 and 1970. In the aftermath of Expo 58, the architects turned to new forms, new techniques and therefore a new form of architecture (Totelin 2019).

In January 1967, CBR requested a quote from Glaverbel for volumes with four curved sides. In November 1967, Glaverbel – via its wholesalers – provided a quote for the supply of 750 210 × 135 cm volumes with four bent surfaces and four rounded corners to the architect Brodzki, who was responsible for the construction of the CBR building. Glaverbel's Stopray was in competition with German and American products. Glaverbel applied a surcharge of 20% per curved side and 20% for the four rounded corners and curved sides, rendering its quote unacceptable to CBR (NAB 2, Glaverbel archives, 26). On 30 September 1968, a letter mentions heated discussions between Glaverbel and CBR, in which the former insisted that CBR should choose its Stopray Gold 40/27 over the American coated glass for the glazing. CBR was not convinced that Glaverbel was making the necessary technical effort to be able to manufacture the custom-made thermopane units using industrial tooling at a cost price that would allow widespread use in buildings that were constructed using the architectural concrete technique (NAB 2, Glaverbel archives, 26). It would appear that the challenge has not yet been taken up! Indeed, "CBR" presents a façade entirely made of molded white cement concrete elements.

On 22 November 2018, the entire building and part of its surroundings were included in a preservation list as a monument and historical site respectively. In 2018, the owner undertook renovation work on the building, including a project to replace the damaged glass. The façade has 756 windows, and 216 glazing units were replaced. To achieve this, an inventory was completed, and identified a "type A" that included the glazing to be replaced immediately, and a "type B" that included the glazing to be changed within the next five years. At the end of the renovation, all "type A" glazing was replaced as well as 50% of "type B". During the pre-project studies, it was found that the glass had been renewed approximately every 10 years. However, to make budget savings, the replacement glass was "filmed" glass and therefore less durable, needing heavy maintenance. Currently, there is still a stock of filmed glazing stored in the building's garage (Roman 2016).

The glazing company in charge of the restoration project ordered 260 panes. The cost of each of these items was twice as high as the production of filmed glazing. Knowing that the original glazing was the most durable, the client opted for this solution. In addition, the announcement of the classification procedure also influenced the decisions relating to the renovation work. The new glazing was placed from the inside and directly set into the concrete, which is why the new element had to have the same dimensions so that it could fit perfectly into the grooves provided for this purpose. The renovation of the glazing lasted one month (Renaud Jacquet 09/19).

5.3 *La Royale Belge: A giant made of steel and glass.*

In 1965, La Royale Belge, one of the largest insurance companies in Belgium, was faced with the imperative need to expand and was forced to move its headquarters to a new building. To this end, the company chose a site in the green outskirts of Brussels, on the edge of the Soignes Forest. In the years 1967–9, architects Dufau and Stapels, renowned for their post-war modernist style and use of modern building materials, built the cruciform building. Construction began in February 1969 and was completed in June 1971 (*La Technique des Travaux* 1971). The eight floors of the cruciform part of the building are clad with 10,000 m^2 of solar glass. This glass was produced by Glaverbel and installed by the company J. Oosterlink. The glazing is set in an aluminium frame produced

Figure 2. Placement of glazing on a wing of the former headquarters of La Royale Belge in Watermael-Boitsfort. Source: the private archives of Benoît Berdoux.

by Chamebel. It consists of two 169.5 cm × 235.5 cm glass panes, 6 mm thick and separated by a 12 mm air gap. The 1626 × 407 cm spandrels are also made in Stopray (*Le verre revue d'information des arts et techniques* 1971). However, they are laminated units consisting of two panes glued together using PVB (Polyvinyl butyral) film, to which the metal film is applied (Parbhoo 15/09/20). The transparent spandrel is placed in front of the ventilated concrete floor slabs at each level, maintaining a specific distance between them. The chosen tint of the Stopray is Gold 40/27, which blends particularly well with the warm colour of Cor-Ten steel. The spandrels were placed prior to double glazing.

On 1 September 1969, the SA and the ED companies appeared to have begun corresponding. François et fils, the SA company CFE, and J. Oosterlinck, wrote to Glaverbel. On 4 September 1969, due to the lack of supplies from Glaverbel, Chamebel was four levels ahead of J. Oosterlinck. On 11 September, the construction work was halted as large volumes of material required for the floor in Wing 3 were missing. On 13 September 1969, the protagonists wrote to Glaverbel, informing them that, for the past 10 days or so, the supplies of Stopray glazing for the cross-shaped building were no longer keeping up with the pace of construction (Figure 2) (NAB 2, Glaverbel archives, 26).

A survey and inventory campaign of all the building's frames was carried out between 2009 and 2011. This campaign made it possible to identify the glazing and to list the different windows according to the various flaws observed on them. The windows were of a defective nature and could not guarantee the technical performance of the original frames. Through the process, the degree of deterioration of the windows was listed, pointing out the cracked and fogged glazing. Following these observations, several interventions were carried out to renovate the façades. Firstly, as Stopray 40/27 glass was no longer being produced at the time of these studies, the Stopray glass present on the gable of the north-east façade, facing the Ten Reuken Avenue, was recovered and reinserted on the long side façades of the different wings of the building in order to preserve the colour unity of the ensemble, while new glazing was integrated on the gable. The new glazing consists of double "infrastop" glass with a copper tint that differs from that of Stopray. These specific recent interventions made it possible to preserve the "spirit" and "meaning" of the building (Chapelle 2013).

Currently on the 4th floor of the cruciform tower, glazing tests can be found that were carried out by the firm AGC. The new glazing will be Stopray and, to imitate the colour of gold, an "on demand coating" has been used. However, it is impossible to achieve the same effect as the original glass without using precious metal. In addition, the restoration team is concerned about another issue: the composition and position of the spandrels give them a different colour than the envisaged glazing, giving them a "rosy" appearance. With today's technology, it is possible to have an entirely uniform façade, but is it also possible that this difference in the colour of the glass was desired and known by architects? In the early 1950s, Pierre Dufau had been using Boussois Thermopane for its thermal and sound insulation properties, and one of his buildings was used in the company's advertisements. At the end of the 1960s, he used the Saint-Gobain Parsol product, which was already in popular use in Belgian construction (Massire 2017). La Royale Belge seems to be the first building for which he considered using reflective glass, a material that became his favourite in the 1970s. It is therefore difficult to determine how much he knew about the material and its possibilities back then. However, the Dufau agency was known for studying the details of the finishing work very precisely (Massire 20/12/20). The Stapels agency had already used Stopray 40/27. Indeed, this material was used on the façade of the new buildings of the Anciens Établissements D'Ieteren Frères S.A. headquarters, located at 50 Rue du Mail in Brussels, which was inaugurated in May 1967. However, in this project this product is not used as a spandrel. The Stapels agency also used this material in the Belgian pavilion at the World Exhibition in Montreal in 1967. And throughout his career, the architect used Stopray extensively in various shades (Inglisa 2017).

5.4 *Buildings that have lost their golden shine*

Unfortunately, some of the buildings that used to have Stopray glazing no longer dazzle us with their presence as they have been demolished or heavily altered following renovation work. Among them is The Astro Tower, situated at Avenue du l'Astromnie 14. Completed in 1976, it was designed by Albert De Doncker (Demey 2008). Following a major renovation – which was completed in 2016 – the building now has new glazing and a new look. The former headquarters of the Fabricom companies, completed in 1972, is another example. Built by the architects André Bauwens, Françoise Blomme, R. Thirion and José Vandevoorde, it is located in Uccle, and currently being restored by the Bureau Architecture Engineering

Figure 3. Façade of the tertiary building located at Square de Meeus n°. 8 in Brussels. Source: private archives of Sophie Vantieghem.

Verhaegen (BAEV). In Charleroi, not far from Brussels, the Albert Centre, also known as the Baudoux Tower, is a skyscraper inaugurated on 11 June 1964, which in March 2005 lost its golden hue (Culot & Pirlet 2015).

5.5 *The uncertain future of Stopray Gold*

Amongst imminent restorations in Brussels is that of the headquarters of the company, D'Ieteren. In March 2019, D'Ieteren expressed its ambition to keep its headquarters in Ixelles, but to move its commercial activities to other sites designed for this purpose. The firm has launched a European competition for the rehabilitation of its historical building. The building, built by René Stapels in 1968, is to be renovated to a "state of the art" standard. It is divided into two parts: the infrastructure and the superstructure. The shell of the superstructure is a curtain wall, a construction process that was widely used in the post-war period. The latter is made of aluminium and two types of glass, including Stopray Gold 40/27 (*La Maison* (7–8) 1967, 229–38). Not far away the main building, at 350–358 Avenue Louise, there is another office building built by the architect Alain Casse, in 1972. It was originally made of Stopray Gold, supplemented with marble stone. Finally, to mention just one example, in Square de Meeus n°. 8 (Figure 3) in Ixelles there is an office building by the architect Michel Barbier in 1973, which has already undergone several renovations, notably, in 1996, when new Stopray Gold was produced for the occasion (Bâtiment, n°. 250: 27–30).

6 CONCLUSIONS

There is an urgent need to continue documenting this type of lightweight façade. Because commercial buildings built between 1950 and 2000 are at a turning point in their existence, without proper studies to document their history, they are unlikely to be preserved. In this context, the Glaverbel background must be highlighted and treated as it contains many valuable plans and information, particularly in the context of current restorations. Stopray Gold is no longer produced. The buildings that still present it are therefore rare as are the valuable witnesses of the history of the product. Stopray Gold 40/27 is an exceptional case, as it is the forerunner of its typology and is undoubtedly the colour that should be most valued.

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Prefabrication and participation by users: A challenge in Italy (1960–1976)

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ABSTRACT: In post-war Italy, research on prefabrication went beyond the functional use of the elements. The theme of modularity, seriality and prefabrication was explored with many nuances: from the desire to combine the theme of prefabrication with the limits and compositional and architectural potential of the systems, to the theme of modular coordination of architecture, which allowed for a greater or lesser number of components, whose assembly could lead to almost endless variations. Unlike other European countries, Italy never opted decisively and in a widespread way for this type of approach. The paper investigates the use of prefabricated systems in real plans for the construction of residential buildings and schools in the north of Italy. The need for middle-class housing in the boom years and requests by the Ministry of Education transformed the theoretical studies and singular experiences into real programmes for construction of prefabricated buildings with the participation of users.

1 INTRODUCTION

“The problem of reconstruction is not a problem to be resolved with moderate coordinated action by sensible, ordinary administration: it is a problem awaiting a solution, at least in Italy, based on revolutionary measures and bold innovations in all areas.” (Calcaprina 1945). So wrote Cino Calcaprina in the first edition of the magazine *Metron* in 1945, stressing the necessity for organic new plans to address the needs of society, conditions of habitability and the backwardness of the housing industry, conditions present before World War Two and even worse thereafter. The need to plan reconstruction, the role of private initiative in those projects, and the need to have houses available within a reasonable amount of time – and “not for our grandchildren, if we keep making eternal houses, with artisanal methods” – triggered a debate centred increasingly on prefabrication, a theme that had been marginal in Italy until then.

This theme had already been addressed between the two wars in detail by influential figures from the world of engineering and architecture. Now, however, it acquired a broader, more diverse dimension. Considered in relation to the housing problem, the controversy became heated, with parties taking sides for or against industrialization of the housing sector – without actually bringing the arguments up to date with reference to the international debate, technical problems, economic questions or the compatibility of their own position – or prejudice – about new methods of construction.

“The Italian housing industry has an absolute and urgent need to review and refine the theoretical and technical procedures that are the basis for the design and realization of buildings. A more rigid and totalitarian economy of materials and labour is the last chance we have left to reduce the terrible and paralyzing disproportion between scarce national resources and the unlimited mass of reconstructive needs” (Nervi 1945). With these words, Pier Luigi Nervi outlined the urgent problems of reconstruction immediately after the war, which compelled Italian architects and planners not only to revise and refine housing but above all to investigate new possibilities and experiment with different methods in order to find possible solutions to the housing problem in a country devastated by wartime destruction.

After the Second World War, the situation in Italy regarding studies of prefabrication and its use in the construction process was highly developed and multifaceted. After an initial phase, characterized by a substantial time lag in this sector (Albani 2012), in the 1950s, a mature approach to the theme of industrialization in building was addressed at numerous national and international conferences, as well as in numerous technical publications and bulletins. Nonetheless, the country’s economic policy prevented development of the Italian systems experimented with between 1947 and 1951, although the idea of resorting to prefabrication to meet the country’s housing needs was widely accepted (Petrignani 1965). The arguments tended in the direction of what was termed “heavy” prefabrication (Koncz, Mazzocchi, Tealdi 1979) in

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which France was at the forefront in Europe (Delemontey 2015). The implementation of the French system by IACP of Milan in the construction of public housing lasted approximately one decade. Superficially, it can be seen as the annihilation of more than 15 years of studies, strategies and policies encouraging forms of prefabrication linked to Italy's cultural, technical and, especially, productive capability (Albani 2013). Although, for its housing construction, Italy opted for well-tested systems that had been used elsewhere, research and experimentation continued regardless, thanks to the influence of a number of architect/industrial designers (Albani 2015) – among them Marco Zanuso (Burkhardt 1994) Angelo Mangiarotti and Gino Valle – who placed this theme at the centre of their own architectural production and contributed to an eventual "Italian" response (Associazione Italiana Prefabbricazione per l'Edilizia Industrializzata 1980).

The experiments in Italy were largely concentrated in two aspects: prefabrication of the load-bearing structure, in particular, in reinforced concrete; and prefabrication of the building's envelope in relation to the interior space. There are several examples in which this prefabrication of the envelope acquired the ulterior role of including user participation in defining the architecture. Specifically, the desire on the part of the planners to actively engage clients in the planning phase opened the way to interesting social, formal and construction considerations.

2 MIDDLE CLASS HOUSING: PREFABRICATION AND PARTICIPATION

2.1 *The economic boom*

In the 1950s, the economic boom in Italy and the consequent expansion of well-being created a climate of great enthusiasm for reconstruction, which, however, had to face the reality of the forces and capacity of the country. The protagonists of the architectural debate of the period participated in this climate, especially in the north, where industries in areas like Lombardy were just discovering their role as drivers of the country's economic development (Bagnasco 2008). Of particular excellence was the production of designer objects for the home, based on an artistic approach and refined craftsmanship (Crippa 2007). The way in which a living space is defined, with the participation of the user, is intimately related to social life and the way in which a social class identifies itself (Caramellino & Zanfi 2016). Thus, active participation in the design offers the possibility of consolidating one's position within an extremely diverse social group (Bose 2008).

2.2 *Angelo Mangiarotti and the residential building in Monza 1968–75*

"My activity in architecture […] I believe to be part of the line of works whose technical reproducibility possesses a notable theoretical importance. It can be said that in this type of expression reproducibility becomes constitutive" (Mangiarotti et al. 1987). With these words Mangiarotti himself, by then over sixty years old, sought to sum up a life of work and research on the themes of modularity, seriality and assembly (Albani & Graf 2019), which went beyond the architectural artefact in its finished and unique aspect (Nardi 1997). It was an activity that was structured and proceeded by means of prototypes representative of a process that sought to define new relations between those who devise, those who produce and those who use architecture and which came to fruition only when the design purpose was transformed into physical reality. Angelo Mangiarotti's work is closely related in many ways to the research conducted by architects, artists, inventors and builders such as Konrad Wachsmann, Max Bill, Richard Buckminster Fuller and Jean Prouvé, who interpreted the concept of "prefabrication", a theme that in the 20th century represented a sort of utopia defined as "industrial". The economy and rationalization of means in post-war Milan provided Mangiarotti with an opportunity to exploit the multiplicity of relations between architecture and technology and, in some cases, through an aesthetic and symbolic dimension, his research went far beyond the functional use of the elements. Mangiarotti interpreted the theme of modularity and seriality with many nuances: from the desire to combine the theme of prefabrication with the limits and compositional and architectural potential of the trilithic system, to the theme of a modular coordination of architecture, in which he found space for a greater or lesser number of components, whose assembly led to almost endless variations (Albani & Graf 2015). In the case of middle-class housing, Angelo Mangiarotti built two buildings near Milan in which he explored the theme of the flexibility of interiors and façades with a view to fostering participation by the inhabitants already in the design phase (Bona 1980). The different ways of living made it possible, therefore, to produce the "unpredictable", the random. The neutral and configurable components included all possible geometrical combinations: continuity, recessed or protruding corner solutions. This was Mangiarotti's way of introducing variation starting from a rigid grid and of interpreting industrialization and prefabrication as a new principle of figuration that does not limit creative activity (Mangiarotti 1977). The building in Monza is the first of two middle-class housing buildings. It has a compact plan, consisting of eight floors and standing isolated on a lot of irregular form, with no relation to the surrounding buildings. The load-bearing structure made of concrete cast on site, whose only fixed elements are the stairwell and the elevator, determines a free plan organized on the basis of a 32cm grid, which allows for complete freedom in the configuration of the apartments. Calculations of the load-bearing structure were made by the engineers Giulio Ballio, Giovanni Colombo and Alberto Vintani of Milan (Bauen + Wohnen 1977). The internal organization of each apartment is reflected in the

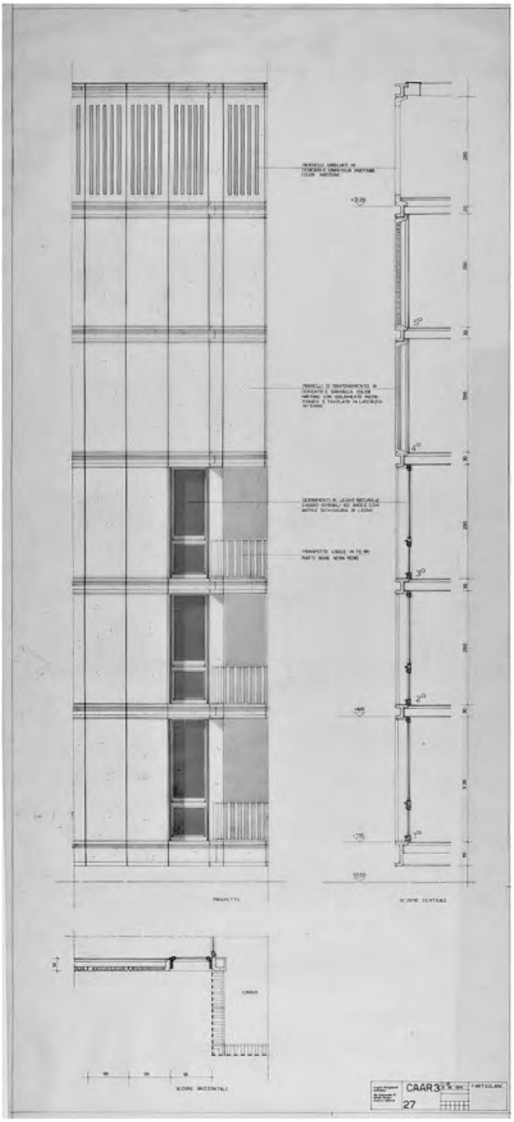

Figure 1. Residential building, Angelo Mangiarotti, Monza 1968–75 (Archive Angelo Mangiarotti, Milano).

overall design of the façade, which is also based on a modular grid of 96cm, in which opaque, glazed or openwork prefabricated panels or balconies with metal parapets alternate, resulting in an elegant and highly articulated composition. The opaque panels are made of reinforced concrete with interposed poly-urethane foam insulation, an outer cladding of Vicenza grit-stone and string courses with C-shaped profiles. The panels of the façade are attached to a prefabricated element that creates a continuous string course. The single façade module allows inhabitants to position the external walls and galleries as desired while it is still under construction. Thus, both the internal distribution of the rooms and the external appearance of the building vary from floor to floor (Figure 1).

Figure 2. Details of façade, residential building in Monza (Archive Angelo Mangiarotti, Milano).

2.3 *Angelo Mangiarotti and the building in Arosio 1974–78*

The building in Arosio, a municipality of Brianza, is the second middle-class residence built by Mangiarotti that combines prefabrication with user participation in the planning phase. The clients for this building were the same owners of an important furniture company for whom Mangiarotti had previously built several factories using prefabricated, reinforced concrete systems. The residence, built on a lot with a trapezoidal shape, is in many ways a variation on the one in Monza. The themes are the same: flexibility, modular coordination, participation by the inhabitants, prefabrication of the envelope (Mangiarotti 1963). Laid out on six floors, the building has a more complex floor plan than its predecessor because of the presence of balconies and more pronounced setbacks, although it uses the same 32 cm grid as that in Monza. Access is provided by a path that traverses the lot diagonally and along a ramp that leads scenically to the semi-basement level, where the concierge's lodge is located (Figure 2).

The load-bearing structure is in traditional reinforced concrete cast in situ with slabs in hollow-core concrete, while the façades are made of panels precast in reinforced concrete with brick powder aggregate, a simplification of the typologies compared to the residential building in Monza. In the last version of the project, the openwork element was eliminated in the upper part and the string course was made thicker to ensure greater durability. The opaque panel in concrete with incorporated insulation envisaged, as in Monza, a brick counter-wall on the inside, while the wooden window fixtures had casements in natural wood with external shutters (Figure 3).

Figure 3. Building in Arosio, Angelo Mangiarotti, 1974–8 (Archive Angelo Mangiarotti, Milano).

3 PUBLIC SCHOOL BUILDING. VALDADIGE SYSTEM AND PARTICIPATION

3.1 *The new middle school. The 1962 school reform*

Law no. 1859 of 31 December 1962 sanctioning the reform of the single middle school is considered one of the most significant laws in the field of public education of the post-war period in Italy. This reform transformed the scholastic system that, at the end of the 1950s, was essentially the same as that in effect between the wars, wherein students could complete their studies after primary school either by studying one additional year or by attending middle school and then any high school. With the reform, the various types of middle school were standardized into one model, the “scuola media unica”, which was free and intended to train young citizens. So began a process of mass education that generated profound changes throughout Italian society (Cambi 2005). The single middle school was the answer to the enormous need for schooling in Italy, which was clearly lagging behind the rest of Europe in this respect. At the same time, however, it created new needs. With the introduction of mandatory attendance for such a vast number of students, existing school spaces proved suddenly inadequate and insufficient in number. It was clearly necessary to initiate construction of new spaces to accommodate the growing number of students. To this end, a national commission was formed to study the construction of the new middle schools, and legislative initiatives were implemented to encourage the building of scholastic centres that would correspond specifically to the needs of the different communities. In this way, the theme of the school became linked to a vision of urban planning in which new constructions are to be integrated into the urban fabric.

This theme also entered into the ongoing debate about architecture. The fervour it generated is demonstrated by the 12th Triennale of Milan in 1960, entitled *La casa e la scuola*, a crucial moment of reflection about the evolution of typological choices for school buildings in which many authoritative Italian and foreign experts participated.

3.2 *The Valdadige system*

Together, the new school reform, public investments and architectural debate triggered a virtuous circle of research, experimentation and proposals of new prefabricated systems to satisfy the growing demand for suitable scholastic spaces. Crucial guidelines for school planning were provided by the Ministerial Decree of 18/12/1975. Many companies and planners grappled with the issue of the development of new construction technologies for building schools. The simultaneous presence of diverse factors, however, determined the success of the Valdadige system, developed by Gino Valle and Giorgio Macola and employed in the construction of more than 30 schools in northern Italy (Virgioli 2016). The prefabricated system is quite sophisticated, while the study of light, colour and space aims to achieve school environments that take into account and enhance the children’s various activities. The *Valdadige – Edilizia Scolastica-Elementari e Medie* catalogue was drafted with the intention of illustrating how the system operated thereby encouraging participation of local administrations in the planning phase. These authorities could thus modulate the system on the basis of the construction site and their particular needs (Figures 4 and 5).

The Valdadige PTK (pillar-beam-vault) system is a punctiform system whose basic components are a 40 × 40 cm pillar, a main beam with an inverted T-section, and a vault ceiling element (*coppella*) with a 2.4 m wide double T-section. The work of architects Valle and Macola used a basic system like the PTK for the school typology, facilitating simple solutions that made it possible to build schools quickly, inexpensively and according to the regulations. Furthermore, all components are clearly illustrated in the catalogue. The pillars are all equal, except in height (single-floor and two-floor pillars), made of reinforced concrete with supports for the beams. There are three types of beams: intermediate beams with an inverse T-section; Z-shaped edge beams to support the ceiling, and ring beams, which are only half beams so that the edge of the structure is uniform. The vaults are made of yielded reinforced concrete, 2.4 × 6 m

Figure 4. Top part of the building (Archive Angelo Mangiarotti, Milano).

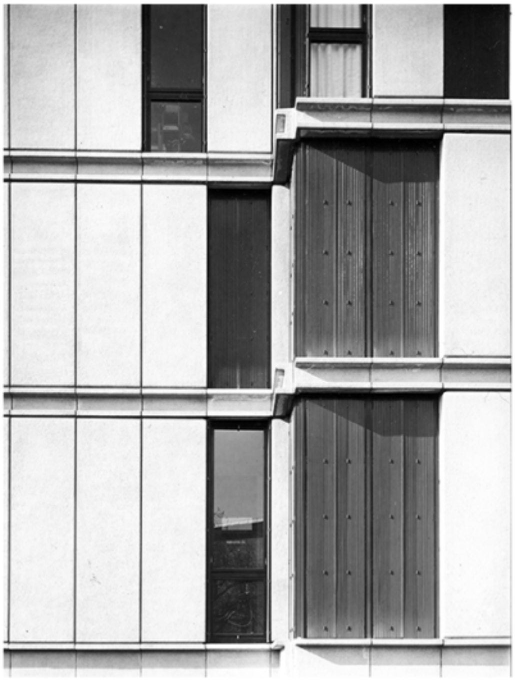

Figure 5. Prefabricated panels of façades (Archive Angelo Mangiarotti, Milano).

for the first floor and 2.4 × 12 m for the roof. The ribs are perpendicular to the longitudinal façades, corresponding to possible divisions of the interior. The horizontal elements are designed to be mounted to the vertical elements by means of mechanical devices and subsequently secured with a supplementary casting. This also guarantees that the structure can withstand an earthquake in areas such as the north-east, which has suffered serious earthquakes in the past (Vitali 2010). The foundations, cast in place, are reinforced concrete plinths on which rests the slab, separated from the earth by a ventilated crawlspace and isolated with a layer of polyethylene foam. The façade panels extend further than the extrados of the ceiling slab to create an edge beam covered with an anodized aluminium flashing. The roof panels are isolated with a 5cm layer of cork placed on top of a layer of polyethylene that serves as a vapour barrier, wrapped in a layer of PVC waterproofing and covered with gravel. The panels that form the flat roof are the 2.4 × 12 m vaults, slightly curved to ensure the flow of water through downspouts in the pillars of the façade. Finally, the façade is made of 22 cm thick concrete panels with expanded clay to meet the standards for isolation in force at the time. The panels can be mounted in a variety of ways, allowing diverse solutions depending on the orientation of the façades. On the east and west façades, the panels can be mounted horizontally to allow for ribbon windows, while on the north and south façades, generally without windows, the panels are mounted vertically. As for the interior spaces, the concrete of the prefabricated elements is left exposed. In the common spaces, the systems are also left exposed whereas the classrooms are provided with a false ceiling to improve the acoustics and are divided from one another with plasterboard walls. Colour plays an important role as well. Valle experimented with acrylic paints with quartz to make the façade panel surfaces bright in contrast with the grey of the exposed concrete. At first, he used metallic grey, as seen in the school in Bissuola a Mestre; then he introduced red for the windowpanes and floors so as to highlight the common space and connecting canopy. The introduction of green, as a complementary colour to red, emerged from the idea of continuing to experiment with colour (Croset & Skansi 2010) (Figure 6).

3.3 *The school in Paisan di Prato*

The first part of the Valdadige catalogue provides information for users to help plan, along with the planner, a school that would meet their specific needs, related to the number of students and the construction site. The school complex called for the organization of spaces into educational units of variable dimensions integrated with the classrooms. The standard floor plans of the primary schools have 6, 9, 12, 15, 20 or 25 classrooms while the middle schools have 9, 12, 15, 18, 21 or 24. The system allowed for users to organize the spaces in a variety of typological layouts, depending on the number of students. The various components of the school (classrooms, cafeteria, gym, technical spaces) could be combined according to a series of diagrams appearing in the catalogue. The result was essentially a

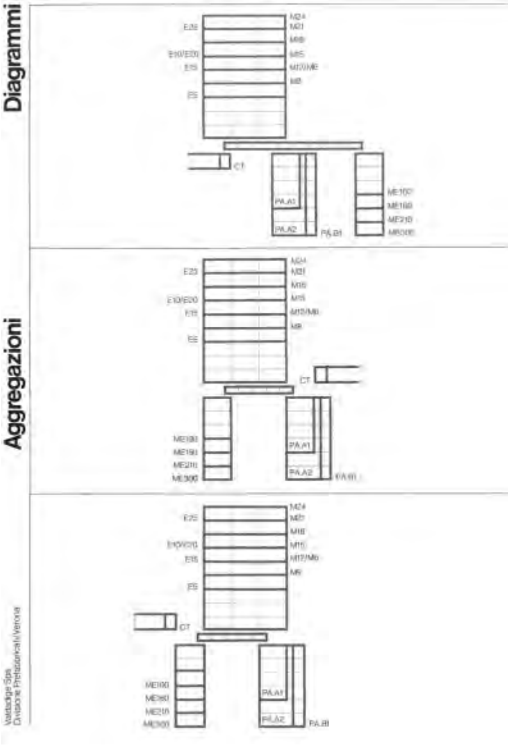

Figure 6. Diagrams of Valdadige prefabricated system (Archive Gino Valle, Udine).

small urban centre that the user (the municipal administration) could define on the basis of the demands and characteristics of the construction site. “This type of organization by nuclei leaves ample space for flexibility in the definition of individual projects regarding both the choice of “containers” and their composition around a connecting pedestrian axis. Furthermore, it is possible to mediate the relationship with the existing urban environment given that the assembling of the “containers” itself organizes the environment, converting the school from a building into a portion of the urban fabric, open towards the exterior and capable of transforming itself by adding onto the basic nuclei or by later aggregations” (Macola & Valle 1977) (Figures 7–9).

The middle school of Pasian di Prato, near Udine, is a school complex designed by Gino Valle himself, applying the Valdadige system. The school’s two buildings develop along a covered east-west pedestrian axis that connects with the street. The teaching building has two floors with 15 classrooms distributed around a large central atrium, 36 metres wide. There are also special classrooms, larger than the others, for the science and chemistry laboratories. The second two-storey structure is 19.20 metres wide (B1 gym type). In these prefabricated school buildings, there is clear evidence in their design of reflections on colour, light and spaces for aggregation that focus on the children’s quality of life. Gino Valle uses colours, especially red and green, that create a contrast with the exposed reinforced concrete surface of the prefabricated system (Figures 10 and 11).

Figure 7. School in Paisan di Prato built with Valdadige system (Albani 2017).

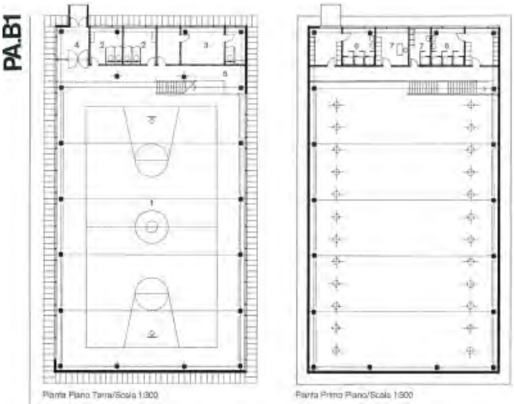

Figure 8. Plans of the school in Paisan di Prato, Udine (Valdadige 1977).

Figure 9. Gym in school in Paisan di Prato, type B1 (Valdadige 1977).

Figure 10. Interiors of the school in Paisan di Prato (Archive Gino Valle, Udine).

Figure 11. Atrium of the school in Paisan di Prato (Albani 2017).

4 CONCLUDING REMARKS

Prefabrication had been accused of compromising the compositional freedom of architecture, but, by the 1960s, this more controversial aspect had been subdued, and prefabricated elements began to be used widely. The topic was approached from many angles in conferences, publications and debates (AITEC 1964), in an environment that had changed from the previous period of precise, tasteful experiments with no real impact on construction plans.

In particular, in the 1960s and thereafter, the theme of industrialization, variation in modularity and prefabrication was explored in the architectural debate by numerous architects/industrial designers, including Angelo Mangiarotti and Gino Valle. Their considerations embraced diverse aspects, including the participation of users in the planning phase. In the society of the boom years, with its widespread well-being and desire for social affirmation, middle-class housing and school design (following the major school reform introducing obligatory middle school) became the territory of experimentation and reflection, in particular with regard to the participation of users in defining these symbolic places for the new society – their own homes and new schools for all.

As regards middle-class housing, the architects of the time were dealing with a clientele distinct from that of the past (Irace 1996), who viewed their home as a source of distinction and social affirmation. However, the presence of the architect created a sort of imbalance within the participatory process that influenced the users, whose lack of architectural culture led them to simply follow the advice of the architect. Regardless, a new approach to the definition of architecture took hold, in which the architects no longer determined the formal definition of the façades or the distribution of the interior spaces single-handedly; instead, they set rules within which the users participated in defining the architecture. There were various experiments in this regard in Italy, including those of De Carlo, Minoletti and Gardella, although they did not combine this approach with prefabrication and the industrialization of the building process.

In contrast, in the process of constructing new schools, especially those realized with the Valdadige system – thanks to the availability of catalogues and repertoires – municipal administrations participated fully in defining the school buildings based on their needs (number of students and classrooms) and the characteristics of the construction site. The Valdadige prefabricated system in reinforced concrete was applied in more than 30 schools in northern Italy, each representing its own variant within the system. In essence, the variety is determined by the participatory process in which the role of the planner and of the construction company is mediated by the possibilities established in the catalogue.

Comparing the two experiences, it can be seen that the schools managed to achieve many interesting and successful results, symbolic of a society in which mass education has become a priority. In middle-class housing, however, results were limited, but, even more importantly, the influence of the planner prevailed at the expense of user participation in the planning phase due to the lack of architectural culture on the part of the owners, who entrusted the design of their homes to the planner.

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History of Construction Cultures – Mascarenhas-Mateus & Paula Pires (eds)

Welcome to the free world! Building materials in post-Soviet Estonia in the 1990s

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ABSTRACT: Collapse of the the Soviet Union in 1991 led to radical changes in societies of former Union Republics as a whole, invariably affecting their construction and architectural sphere. The aim of the current paper is to show how the socio-economical transformations totally changed the usage of building materials in less than ten years, having a strong impact on architectural culture. During the Soviet period, the construction sector was highly standardised and strictly controlled, building materials were limited in variety and often scarce. In the 1990s, the former Union Republics were opened to free-market economy and many common building materials already used around the world for decades finally became available in Eastern Europe. The transformations in usage of building materials are examined in the case of Estonia, one of the most Western-oriented countries of the former USSR, where the changes in the 1990s were especially rapid.

1 INTRODUCTION

The architecture of every decade is shaped by that period's favourite construction materials and techniques. In a free-market economy, shifts from one preferred material to another are usually smooth, as changes in the use of various construction materials are due to innovation, and broader recognition of new materials normally takes time. The collapse of the Soviet Union offered a unique chance to observe what happens when a centralised, planned economy is replaced by a free-market economy. In scarcely five years, in the early 1990s, the usage of building materials and the appearance of architecture were radically changed. This paper reflects on these transitions in the case of Estonia, one of the westernmost and most Western-minded former USSR states, where the changes were extraordinarily rapid. However, the same kinds of processes could be observed elsewhere in Eastern Europe.

To make the general context more comprehensible and to describe the typical construction solutions and widely-used materials in Estonia at the time, the paper begins with a brief introduction to the economic and construction market situation in the late 1980s. The analysis of changes in construction materials and construction culture in general is grounded mainly on an examination of 1990s newspapers and magazines, combined with memories and statistical data. The construction history of the 1990s is still a largely unexplored field. Although recent studies are focusing on the transitions of the architectural culture (Ruudi 2020), changes in the usage of building materials have so far been unexamined. The current paper aims to take a first step in drawing the most characteristic lines of this aspect in this interregnum period.

2 STARTING POSITION: THE CONSTRUCTION SECTOR IN ESTONIA IN THE LATE 1980S

Construction in Estonia in the late 1980s could be summarised by such keywords as 'centralised planned economy', 'limited choice of construction materials' and 'shortage'.

The economy of the Soviet Union was based on state ownership and highly centralised, economic planning. However, one must admit that a certain entrepreneurial freedom had already been tolerated during the waning years of Soviet rule. For example, from 1987, small private businesses were allowed in order to relieve the shortage of necessities. In the first two years of independence, around 1,000 small companies were established in Estonia. Cooperative enterprises with foreign partners were allowed as well. In the current context, it is worth mentioning that the first such company in Estonia was the paint producer and retailer, *EKE-Sadolin SP*, established by the Finnish enterprise, *Sadolin*, and the Estonian state-owned construction union, *Eesti Külaehitus* (Esimesed õppetunnid 2019). Setting up private businesses and permitting international business relations opened the way to the free-market economy.

During the Soviet period, planning, designing and building were concentrated in state-owned design and construction firms. Standard-design buildings that could be constructed from assembled elements were favoured. The most preferred building material in the

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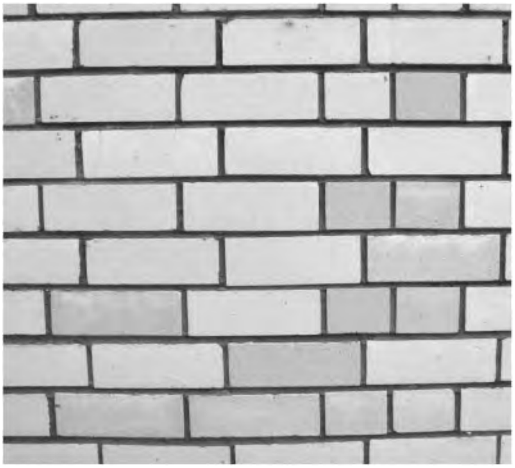

Figure 1. Calcium silicate bricks were widely used in 1980s.

USSR was prefabricated concrete. Brick wall constructions were also widespread, but the use of metal in buildings, for example, was strictly limited. Metal constructions were possible in only a few unique one-off designs. Elsewhere, the buildings had to be built using standard, reinforced concrete components, even though a metal construction may have been more economical. Metal sheets as a facade covering were almost unused. Metal was used infrequently in building construction because metal was intended for the arms industry in the USSR. Designers had to work with a limited selection from product catalogues (e.g. catalogues of reinforced concrete and aerated concrete products), which presented the available standard components. The finishing of exterior walls was also limited, although there were regional differences. In Estonia, there was roughly a choice between plastered and painted walls, exposed brick walls, prefabricated gravel-coated concrete panels or limestone cladding. As a result, the dominant colour of late Soviet housing in Estonia was a pale grey accented with red brick or some modestly coloured wooden details (Figure 1).

In addition to the limited selection, the construction market was also haunted by shortages. An individual builder, outside the state system, was especially affected by the unavailability of materials and had to be incredibly inventive to access the necessary construction materials for building a home. In theory, the owner-builder should have been able to buy building materials from state shops, but, unfortunately, only a portion of what had been ordered ended up in the shops. Accessibility varied from material to material. In 1989, for example, 77.8% of orders for asbestos cement sheets were fulfilled, whereas only 38.6% of orders for reinforced concrete and only 20% of orders for ceramic furnace tiles were supplied (Gailan 1990). The majority of construction materials used were of local origin. The few imported products available were challenging to acquire (Figure 2).

Figure 2. The ideal of Soviet architecture was a standard design building made of assembled elements.

3 WHAT CHANGED IN FIVE YEARS?

The late 1980s and early 1990s are regarded as a transition period, when Estonia transitioned from a totalitarian state to a democratic nation, from a state-planned economy to a free-market economy. A large number of private companies were established in just a few years. Of the more than 60,000 companies operating in the Estonian market in 1995, 4,311 were operating in the construction sector (the retailers of building materials are not counted herein) (Eesti statistika aastaraamat 1995).

The former dearth of materials turned into an oversupply. The market was flooded with dozens of virtually unfamiliar modern building materials, and this, in turn, significantly changed the appearance of buildings. Locally-produced, primary construction materials vanished or were replaced with new types of products. The production of prefabricated, reinforced concrete elements and wall materials (silicalcite blocks and panels as well as calcium silicate bricks) decreased about 6–7 times while the production of asbestos cement plates, soft roofing materials and mineral wool was terminated (Eesti statistika aastaraamat 1995). Meanwhile, newly imported building materials, such as different facade cladding plates, steel roofing sheets, laminate flooring, drywall and paintable wallpaper entered the market. Some new brands, such as *Makroflex* polyurethane gun foam and *Gyproc* drywall, became so popular that the brand names became

Figure 3. *Makroflex* was one of the most popular brands in Estonia in 1990s.

synonyms for all products of the same kind. Some gaps in the accessibility of various materials were, however, natural. For instance, no mineral wool was for sale in Estonia in 1994 as local production had ended and importing had not yet begun (Saluveer 1994).

An economic crisis was evident in the first years of 1990s, causing a significant decline in construction. At the same time, a weird situation emerged. Theoretically, almost every building material one could dream of was now available, but most people lacked the money to buy them. So, at least individual builders still favoured local materials, which were much cheaper but also poorer in quality. It was estimated in 1994 that about only a quarter of a volume of building materials used by the individual builder was imported. However, the cost of imported and locally produced materials could be shared 50-50. The imported building materials were used mainly for interior finishing (Saluveer 1994). This change in materials was most visible on the buildings of newly successful companies and their owners, who had the financial freedom to develop architectural solutions (Figure 3).

Figure 4. The model of the *Baltlink* hotel.

4 CHANGES IN ARCHITECTURE

Although knowledge of new materials spread rather quickly, their real application took time. The architectural designs and built houses of the late 1980s and early 1990s in Estonia are well documented. Thorough architectural overviews for each year list almost all the completed buildings, as well as the most remarkable designs. According to these books, it could be stated that the new foreign materials were already being used in architectural designs at the very beginning of the 1990s, while ‘Soviet materials’ in completed buildings were still dominating in 1993. One main reason for this contradiction is, of course, the time gap between design and construction. Most of the buildings that were finished in 1993 were designed some years earlier.

The unbuilt designs are worth examining, however. A *Baltlink* hotel (Figure 4) in the city centre of Tallinn is perhaps one of the best examples. Designed in 1990 and never built, it was labelled the ‘turning point in the integration of Estonian architecture with Western architecture’, referring mainly to the materials that the builders were planning to use. It was supposed to be an 11-storey building with exposed concrete facades combined with colourful metal sheets, mirror glass and steel pipe truss (Arhitektuurikroonika’90 1993).

Perhaps the most visible change in building materials was the expanded use of metals. A considerable change entailed the use of steel roofing instead of asbestos cement plates. In 1993, steel roofing was admittedly not yet common but was gaining popularity (Kallast 1993), and by the 2000s had become the most popular roofing material. Even more significant was the use of facade metal sheets, which shaped both utilitarian and elitist architecture. The iconic architectural building of the era is the building of the *Nissan Centre* in Tallinn (Figure 4). Brick walls are hidden under a smooth, black tinplate surface that declares its belonging to the free world by showing no vestiges of the Soviet past (Kalm 2002) (Figure 5).

The architectural style of warehouses and industrial buildings also changed totally – the new approach was

Figure 5. *Nissan Centre* in Tallinn.

Figure 6. The end wall of an insulated apartment building covered with colourful profile metal sheet.

to use a steel truss structure and to cover the walls with profile metal sheets instead of using prefabricated concrete elements. The profile metal sheets also became one of the most common materials for wall finishing of residential buildings while installing external insulation (Figure 6).

Descriptions of the material changes in architecture in 1991 cannot be only one-sided. To say that grey and dull Soviet architecture was replaced by colourful, shining and high-quality Western architecture would be an obvious overstatement or even an outright lie. Although the imported building materials were of good quality, the work was still done mainly in the same manner as in past years, which is to say that the construction quality on the whole did not improve much. Only a few new buildings were erected in these years. However, renovation works were carried out on a large scale. The 1990s brought a new expression to the Estonian language: 'euro-refurbishment'. At first, this was supposed to mean refurbishment done with imported and high-quality materials. In just a few years, however, it turned into a synonym for fast and cheap, anonymous-looking renovation works. As property owners lacked time and money, the materials and construction technologies were much the same. The inner walls were set straight with drywall, then painted. The floors were covered with laminated flooring, and the appearance of the ceiling was improved with a suspended ceiling. Standard plastic windows and metal doors replaced the original wooden doors and windows. So, one could argue that the monotony so characteristic of Soviet architecture did not disappear but only changed its material expression (Figure 7).

Figure 7. Plastic windows were desirable in 1990s and many original wooden windows were replaced by them.

5 ARCHITECTS AND A NEW CHOICE OF BUILDING MATERIALS

A topic worthy of further investigation is how architects and interior designers adapted to these new materials. A brief analysis of the media of the 1990s indicates that there were some challenges involved in this transition to new materials. The major problem was that inexperienced local professionals no longer had to choose their materials from a limited number of catalogues; their options had increased significantly. As a result, wealthier and more knowledgeable clients, for example, often preferred to hire foreign interior designers (Kodres 1991). Builders complained that the architects tended to choose products from randomly found colourful catalogues, without knowing whether such materials were available and without taking into account the products' characteristics (Milli 1995).

6 ARCHITECTS AND A NEW CHOICE OF BUILDING MATERIALS

Estonia faced a number of rapid transitions at the end of the 1980s and into the early '90s. Changes in the socio-economic structure led to changes in the usage of building materials. The knowledge of new materials spread quickly, and architects wanted to use them. Due to the economic crisis of these years, the new materials were applied mostly in renovation works and interior design. Perhaps the most visible change in architecture on an urban scale was the application of metal materials as construction elements as well as roofing or finishing plates. However, the symbols of the era may be *Makroflex* gun foam and *Gyproc* boards, which remain in the everyday Estonian language as synonyms for all polyurethane gun foams and drywall.

This paper aimed to take a first glimpse at the changes that occurred in the construction sector – and especially in the usage of building materials – after the collapse of the Soviet Union. However, the topic needs further investigation and contextualisation. A comparative study of different, former Soviet states could be useful, as might an examination of how these same materials were approached in the different cultural context of Western Europe. The relatively small time gap would make it possible to use oral sources, which are invaluable in understanding why and how particular materials were used and determining their cultural significance.

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History of Construction Cultures – Mascarenhas-Mateus & Paula Pires (eds)

Demolishing the city, constructing the shoreline

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ABSTRACT: During Toronto's large-scale urban renewal (1950–70s) and economic-led redevelopment (1980s–90s), significant swathes of the city were demolished, making way for modernist superblock housing, new institutions, and civic landmarks, producing tons of demolition material. As these demolition materials were deposited along the shore of Lake Ontario, they solved a material disposal problem, but they also constructed new real estate and landscapes of recreation and leisure. This paper explores relationships between demolition and construction activities in post-war Toronto in three registers: 1) as cyclical urban processes of development and destruction; 2) as the demolition industry shifts from salvage to wreckage model; and 3) as shifting perceptions and composition of shoreline-bound demolition material shaped the Lake Ontario Shoreline. Demolition is an easily overlooked, yet intrinsic, dimension of construction history; its study offers windows into the entanglements between processes of urbanization, construction culture, and cycles of materiality.

1 INTRODUCTION

On hot summer days, temperatures in Toronto easily climb towards 35 degrees Celsius. When dense paved surfaces trap and radiate heat, urbanites flock to the water's edge. On days like this, we make our way to a small crescent shaped beach on the north-side of Ontario Place, three man-made islands connected to the mainland by a short bridge. Wading-in, we find relief in the cool water. The footing is smooth but uneven: what looks like a coarse pebble beach is actually a mix of brick, concrete and stone, round and slippery after 50 years.

All along Toronto's shoreline it is common to notice fragments of building materials softened by water and time. Indeed, since the 1850s, Toronto's lakefront expanded with, as Mark Fram writes, "the dirt and rubble excavated from tens of thousands of basements and sewer tunnels, as well as with chunks of demolished buildings and immense volumes of sand sucked up from the harbour itself" (Fram 2008, 258). Toronto's shoreline indexes the city's cycles of demolition and material deposition. While narratives of urban development in Toronto often focus on incremental waves of construction, this paper convenes on construction's necessary counterpart: demolition.

Within histories of construction however, demolition is often neglected. Christine Wall acknowledges that "although usually overlooked by historians … the demolition and construction process is integrally related to the wider landscape of social and urban change" (Wall 2018). Despite this gap, the technical, social, and ecological implications of demolition have motivated notable activity in the fields of building science and environmental and heritage conservation (Creba 2019; Gorgolewski 2018; Ross 2020; Thomsen et al. 2011). More broadly, there is growing attention to the volume, persistence, construction and other anthropogenic materials and their socio-ecological consequences in an era of climate change (Dibley 2012; Smil 2014).

Meanwhile, examples of relationships between construction and demolition can be seen throughout history and geography, where structures were dismantled to express political prowess (Kostof 1982), mine for material, or reference demolished structures in new buildings (Frangipane 2015). In the modern era, this relationship is expressed as "creative destruction", an economic concept coined by Joseph Schumpeter, but popularized by the geographer David Harvey, where demolition is understood as an inevitable process for new development within a capitalist system (Harvey 1989; Schumpeter 1942).

In this paper, by connecting the destruction of one built form (urban demolition) with the creation of another (shoreline deposition), we focus not only on how construction activities are tied to the devaluation and destruction of pre-existing structures and communities, but also on the subsequent landscapes which are built from the demolition debris. In doing so, we reflect on the need for critical histories on the relationship between demolition and urban development.

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Heidi Schopf and Jennifer Foster have examined Toronto's successive cycles of assembling, demolition, and deposition of building materials through an archaeological and geographical analysis of the Leslie Street Spit – which contains many fragments of the city's architectural past (Foster & Schopf 2013, 2017). Our study builds from these important insights and looks at successive waves of construction and demolition in Toronto, Canada, during the post-war era at three scales: urban, professional, and material. At each scale we see how urban planners, developers, demolition technicians, environmental engineers, engaged citizens and the material itself play a role in defining the shape of the city through both its destruction and expansion. Finally, this case of Toronto's construction and demolition contributes to limited scholarship on Toronto's demolition history. Scholarship on demolition processes has the potential to reveal potentially overlooked dimensions of construction history, and we argue for the inclusion of scholarship on demolition within construction history.

2 A GROWING CITY

When asked why Teperman Wrecking company grew rapidly from a workforce of 80 to 700 men in the 1960s, Jordan Teperman – fourth generation in the demolition dynasty – responded simply, "cities were expanding". Though this may seem obvious to him, Teperman recognizes an easily overlooked reality: the growth of the city promoted the growth of an industry responsible for tearing it down. In Toronto, Canada – as in many other large cities in North America and worldwide – the second half of the last century was a period of unprecedented change and growth, marked by the large-scale clearance of urban landscapes.

Following the Second World War, urban planning agencies sought to remake the urban environment. As Toronto's population and economy skyrocketed, so too did its skyline. Dense government funded housing developments, modernist skyscrapers and multi-block shopping centres were erected to replace their low-rise predecessors. Meanwhile, the material generated through demolition and excavation accumulated in the form of shoreline developments, expanding the city.

One 1981 article framed this growth as "land reclamation," noting that the City of Toronto had expanded by 8% in area, adding 2000 acres over the century (Allaby 1981, 68). And while the practice of "lake-filling" to extend the city's port, rail and industrial lands had taken place since 1850, in the post-war era lake-filling with demolition material would come to define Toronto's contemporary shoreline (Allaby 1981, 68). What follows is an exploration of the forces which influenced this tandem process of construction and demolition at an urban scale.

Adapted throughout Europe and North America, "urban renewal" planning agendas called for the demolition of large swathes of older, usually privately-owned (expropriated) housing, and replacement with housing (some government-owned), often high-rise apartment blocks. Demolished neighbourhoods were often poor, racialized, and politically less-empowered. "Renewal", for many, meant the devastation of their communities and social fabrics. Language used to describe this era often evokes the literal demolition processes, as communities were "cleared" and "razed". "Bulldozing", notes urban historian Richard White, "is the verb most commonly used for the process [of urban renewal], whether or not bulldozers were actually employed" (White 2016, 6).

Regent Park – perhaps the city's most well-known example of urban renewal – saw the expropriation of about 3700 residents, the clearance of 69 acres, and construction of "a true modernist superblock" operated by the Toronto Housing Commission (White 2016, 12). By the time families began to move into Regent Park in 1957, the city was already busy drafting plans following recommendations of a large urban renewal study, completed the previous year. In the years that followed implementation faltered with bureaucratic and fiscal complexities, and planners shifted to a "pockets" approach, clearing and redeveloping more targeted areas (White 2016, 17). Nonetheless, other housing projects, such as Moss Park and Alexandra Park, were developed following this model, fueled by a wave of funding in the mid-1960s.

This development, and its associated community destruction, was increasingly met with citizen resistance. "This resistance," notes White, referring to an emerging heritage conservation and citizen-led planning processes, "rather than the renewal plans themselves, is the best-known aspect of Toronto's urban renewal history" (White 2016, 18; Filion 1999, 424). Responding to these shifting cultural sentiments and professional conventions, the federal government soon ceased its funding and other agencies followed suit. By 1970, urban renewal's moment had passed.

Meanwhile, a whole other set of land development strategies were playing out at the water's edge. For nearly five decades, the Toronto Harbour Commission had been seeking permissions, funds and land on which to develop a second harbour. Distinct from the primary harbour sheltered by Toronto Island this new outer harbour – later called the Leslie Street Spit – promised to enhance commercial, industrial, and institutional activity by allowing greater access to a larger variety of ships.

After nearly a decade of studies and the formal adoption of policy, in 1960 the Commission embarked on constructing a breakwater necessary to shelter this future harbour. While a conventional breakwater would have been prohibitively expensive to build, the Commission began to experiment with using the growing amounts of material generated through the demolition of existing buildings and the excavation for new buildings throughout the city. This unique circumstance, along with the Commission's "pragmatic and flexible" approach enabled them to finally launch the project, before it was clear what specific shape or uses it would have (Merrens 1988, 100). Indeed, with too much demolition material, and too few dump locations, shoreline dumping offered a waste-management solution (Allaby 1981, 71). By providing disposal so close to the demolition site, the creation of the Leslie Street Spit not only facilitated urban development by easing a significant barrier to demolition, but became grounds for innovative engineering techniques, regenerative ecological habitats, and set a precedent for the creation of several new landforms along Toronto's shoreline.

In March 1969, construction began on Ontario Place, which combined modern construction with lake-filling practices. Inspired by Montreal's Expo '67, Ontario Place was an ambitious design for an exhibition park which would revitalize Toronto's waterfront, showcase modern design, and assert provincial fortitude. Over the course of 26 months, over 9000 truckloads of fill were transported to the shallow waters off Toronto's western shore. When it opened in 1971, Ontario Place welcomed visitors to three reclaimed islands, arranged around a cluster of five glass and steel pods (Gemmil 1978, 9). In this context, both urban renewal and waterfront revival hinged on demolition and the material it generated.

"One of the best things Toronto did in the postmodern era", write historians Dendy and Kilbourn, "was to turn again to the Bay and the Lake" (Dendy & Kilbourn 1986, 265). Providing a new site in the planners' vision of a park system stretching across Toronto, the opening of Ontario Place marked a broader shift towards public space and citizen engaged planning (Merrens 1988, 100). Articulating this vision further, in 1972 Canada's first national urban park, Harbourfront, was established in an effort to reclaim land from the private use of industry, shipping and rail, and encourage Torontonians to consider the waterfront an integral part of the city (Dendy & Kilbourn 1986, 265).

Despite this new orientation, between 1970 and 1980 the rapid pace of demolition in Toronto continued as the city entered a period of economic boom. In the downtown core, late 19th-century and early 20th-century landmark buildings were demolished and sent to the Leslie Street Spit. Analyzing the material deposited during this period, Heidy Schopf and Jennifer Foster note, "the rubble of the 1980 zone at the Leslie Street Spit represents a shift in the city's planning practice where capitalism and entrepreneurship played more predominant roles" (Schopf & Foster 2013, 18). This "business friendly" planning approach was reflected in the built form where high-density office buildings became markers of success. During this period the construction of four of Toronto's most well-known landmarks – the CN Tower, Skydome, Eaton Centre and Harbourfront Centre – launched the city onto the world's stage. All large structures requiring significant demolition, these developments represent the broader aspirations of planners and developers, unfettered by the prospects of the new, or what to do with the old.

Perhaps the sharpest break with urban renewal processes, according to Pierre Filion, is evidenced in the growing role of public participation. Protesting the social upheavals and neighbourhood destruction of urban renewal, planning activists brought housing poverty, historical preservation, and environmental crises to public attention (Filion 1999, 424).

From 1971–84, lakefilling was carried out in two phases to form Humberbay Park, a reclamation project which would open adjacent land for development while also appealing to public interest in ecology (Dendy & Kilbourn 1986, 255). Integrating the lessons learned at the Leslie Street Spit, the design of Humberbay Park followed an asymmetric, organic plan appearing as Allaby writes, "as though [it] had randomly sprouted from the shoreline" (Allaby 1981, 71). Over 14 years, Humberbay Park grew by receiving 51 million cubic metres of fill. When the park opened in 1984 it served both commercial and public interests by expanding the land base for condominium development and boat mooring, and also by offering access to parks, beaches and fish and wildlife habitat (Crombie 1992, 155–6).

Meanwhile, growing scrutiny also prompted a series of studies to explore the environmental impact of lakefill developments. Recognizing Lake Ontario as both the source of the city's drinking water, and the location in which it dumped its contaminated building materials, respondents to a 1991 poll noted "Pollution" to be their top waterfront concern (Crombie 1992, 157). In 1992, the provincial Ministry of Environment published the *Fill Quality Guidelines for Lakefilling in Ontario* (revising guidelines first established in 1976). Without the authority to legislate lakefilling practices, the report advocated for erosion control and greater review of lakefill material composition.

Transforming from waste to resource, the use of material generated through demolition reflects shifting approaches to planning and development at an urban scale. Linking the processes of subtraction and addition, as Teperman did, we may understand the ways in which demolition played a role in both the city's construction and destruction.

3 THE RISE OF WRECKING

In UrbanToronto.ca, an online forum dedicated to local development, users comment and reflect on the city's endless state of transformation. "As a kid in the 80's" writes one user, "I clearly remember driving around the city with my parents and seeing Teperman or Greenspoon demolition hoarding all over the place, especially in the older parts of the city. It was both fascinating and depressing to my eyes" (urbantoronto, 2020). Indeed, images of the city in the 1960s, 70s, 80s and 90s are dotted with the orange and green signage of Teperman and Greenspoon wrecking companies. In one grainy photo posted to the forum, a red-brick building displays a hand-painted sign which

Figure 1. Early Teperman Wrecking signage advertising materials for sale. Photo by Davidackerman, posted to urbantoronto.ca 18 Oct 2010.

reads, “Wrecking by Teperman; All Materials for Sale” (Figure 1). “Here’s a note from Teperman demolition [on] their signage” another user comments below, “the pic was 1958/1959. The Long T was the 1960s. Funny story …an editor from New York *Times* advised one of the Tepermans to remove the building materials for sale and leave wrecking. A little hint went on to be a big marketing hit”. As the commenters reference, Teperman’s now iconic logo has an elongated capital T that as a third forum user notes, “appears to be more of a double ended wrecking/pry bar” (Figure 2).

While seemingly insignificant, this change in signage reflects larger technological and cultural shifts within the demolition industry. As demolition activities boomed, demolition companies like Teperman’s shifted their business models: what was once a business of taking apart buildings and selling those salvaged materials, became about wrecking. As demolition scaled up, companies introduced new machines, technologies, and methods for taking buildings down. Combining the need for speed and efficiency with declining social and economic values for reclaimed building components, this transformation also resulted in the creation of a whole new type of material: rubble, a mix of demolition debris made of various components.

As with Teperman’s signs, terminology and technology are linked with nuance. It is important to clarify that while *salvage* and *wrecking* are presented above as distinct processes, they are often entwined. Although the term *wrecking* has historically been used to describe a spectrum of activities, including demolition by implosion or wrecking-ball as well as partial or full deconstruction and salvage, here, these terms are used to distinguish between nuanced demolition processes and outcomes. Whereas *salvage* is a more careful process of disassembly in which materials are reclaimed for future use, *wrecking* refers to the destructive machine-facilitated demolition akin to the processes we see today.

City of Toronto Archives | Fonds 1526, File 10, Item 48

Figure 2. Teperman Wrecking’s revised signage seen mounted to hoarding of a demolition site. Source: City of Toronto Fonds, 1526 File 10 Item 48.

In *Rubble: Unearthing the History of Demolition* (2005) Jeff Byles illustrates this transformation by accounting the technical evolution of the demolition trade in North America. Chronicling the lives of “destruction artists” and the buildings they slayed, *Rubble* describes the shift from the start of the 20th century, when “wreckers” competitively participated in *hand-wrecking*, taking apart buildings so that materials could be carefully salvaged and re-sold. In the decades of accelerated growth and destruction that followed, demolition companies stopped hand-wrecking and began to integrate the use of wrecking balls, bulldozers and dynamite (Byles 2005, 69).

Just as the tools-of-the-trade evolved, so too did the products. Whereas early wreckers turned a profit by extracting durable building components (bricks, steel beams, marble, granite, plumbing fixtures, pipes and especially wooden timbers), by the 1920s, changing labour standards, building techniques, and materials negatively impacted the viability of this technique and the subsequent reuse of materials (Byles 2005, 43). Increased use of cementitious mortars, complex glues and curtain-wall assemblies in modern construction made demolition considerably more challenging (Byles 2005, 46). Requiring more time and effort while yielding fewer salvageable components, the overall value of demolished building materials in the post-war era declined while the practice of dumping demolition debris into lakes and landfills increased (Byles 2005, 47).

In Toronto, Teperman Wrecking followed a similar trajectory. Established in 1918, the company formed when Nathan Teperman (great-great grandfather of Jordan) demolished a chimney in the family's Jewish bakery and was offered payment for the remaining brick. Over the next 40 years, Teperman Wrecking grew – teaming up with local developers to clear sites and establishing a network of salvage yards where up to 95% of the architectural materials generated through demolition were sold for profit (Interview, Teperman, 23 Oct 2020). Jordan Teperman tells of how people would visit the company's multiple salvage yards to search for particular building materials for their home repair and renovation projects.

While before the 1960s, most equipment used for demolition was ordinary construction equipment such as loaders, trucks and cranes (Diven & Shaurette 2010, 103), Jordan Teperman notes how his family's company had long innovated their own tools and techniques. He recalls his grandfather lifting a rubber-tire backhoe to the top of the building with a crane and attaching a hammer to it. "He would sit up there just breaking the building all day" (Interview, Teperman, 23 Oct 2020). The business of demolition required finding people skilled in taking buildings apart by hand. Jordan Teperman recalls how his family would employ Mennonite people from outside of the city. In exchange for labour, these workers would be offered the tongue and groove flooring, limiting the volume of material that needed to be sold.

Specialized machinery evolved with the demolition industry's rise. Of these, the bulldozer is perhaps the most iconic. Connecting the tools of demolition with the culture that powers it, Francesca Russello Ammon's book *Bulldozer: Demolition and Clearance of the Postwar Landscape* (2016) traces the historical rise of the bulldozer, as it facilitated a "culture of clearance" where the bulldozer played a significant role in the transformation of the contemporary North American landscape both in war and urban development (Ammon 2016, 5). Just as war-time advertising victoriously depicted the bulldozer removing rubble from destroyed cities overseas, processes of urban renewal positioned the bulldozer as a tool to "clean-up" neighbuorhoods occupied by marginalized communities at home (Ammon 2016, 146). Exploring popular descriptions of the machine in children's literature, advertising and high art, Ammon demonstrates how the bulldozer permeated the collective psyche and became a tool that enabled new construction by celebrating and implementing large-scale destruction.

In the 1970s, equipment manufacturers began to design various attachments and produce specialized tools. Backhoe loaders reversed to become front-end loaders offering operators more visibility and control (Diven & Shaurette 2010, 103). In keeping with these trends, Teperman Wrecking developed more sophisticated demolition techniques with the acquisition of hydraulic excavators (Interview, Teperman, 23 Oct 2020).

Figure 3. The cover of *Demolition Age* magazine celebrates Teperman Wrecking company's 65 years in business, foregrounding the industry's new tools and Toronto's iconic CN Tower in the background. Source: Teperman-demo.com/media.

As the demolition industry grew internationally, it also professionalized. In 1973 the National Demolition Association was established to represent a growing number of contractors. In July of 1984, Teperman Wrecking was voted Demo Contractor of the Month and featured on the cover of the Association's monthly publication, *Demolition Age* (Figure 3).

Despite the increasing professionalization of the industry – and orientation towards wrecking (and away from salvaging) – demolition companies continued to separate some material for salvage. Select building components continued to be salvaged, but often only those that were deemed to have ornamental value. The wreckers themselves were interested in exploring a spectrum of values for the materials within each building.

For example, recognizing that the value of materials might be worth something to others, during the 1970s, Marvin Teperman trucked select materials otherwise destined to become rubble to a large plot of land on the Scarborough bluffs called Guildwood. There, owners Rosa and Spencer Clark hired architects, engineers, and a stone mason to reassemble the pieces into large sculptures. The 1972 demolition of the famed Toronto Star Building is one example of a structure in which relics were separated from rubble.

By the 1990s, separation was motivated by another trend: recycling. While the economics of salvage were a harder sell, increased awareness of the effects of contamination led to the swift introduction of regulations and pushed recycling to become an important practice which again re-defined the demolition industry. Separating steel and concrete from the rubble also led to new demolition practices, where interiors were "gutted" first with the remaining building demolished then sorted (Diven & Shaurette 2010, 127). Materials were then sold to manufacturing companies who integrated crushed concrete into new aggregate and road material, or melts and reprocess steel at a mill. Offering a way for demolition contractors to recover some costs, and appeal to environmental concerns, the rise of recycling nonetheless affirmed wrecking methods, and continued to generate fill.

Responding to the demands of development, transformations in both the culture and practice of demolition can be seen here through the evolution of its tools and techniques. While formalized processes and professionalization of the industry led to increased efficiencies, the shift from salvage to wrecking represented a fundamental re-valuation of existing building materials and the emergence of a new one: fill.

4 FILL POTENTIAL

"Our family had a formula" recounts Jordan Teperman, "in the 40-yard bins, there's air between the rubble at a (swell) factor of 1.5 meters. Punch it down when you're filling up a bin, and there's 10" (Teperman, Interview 23 Oct 2020). Describing the innovation in transporting volumes of material to the dump site, this account illustrates the way the efficiencies in rapid site clearance were privileged over the integrity of the material itself. Following this material from the demolition site to nearby shorelines for deposition, in this section we trace how conceptions of "fill" transformed through the latter half of the 20th century.

Material has been deposited into Toronto's lakefront since the city was founded for various reasons: to make new real estate, to solve waste problems and often a combination of the two. As lakefilling increased in the latter half of the last century, so did interest in the material composition of this fill. Looking at both the substance as well as the shifting definitions of "fill" through this period, reveals how changing environmental attitudes and engineering advancements worked to redefine from waste into a construction material in its own right.

In their archeological investigations of depositions of the Leslie Street Spit, Schopf and Foster note the irregular composition of rubble delivered to the site in 1964 (Schopf & Foster 2013, 5). Indicative of the loose dumping regulations of the time, the rubble contains high levels of household debris suggesting that homes were demolished before they had been cleared of their belongings (Schopf & Foster 2013, 7–8).

Challenging the notion that only "clean fill" was deposited at the Spit, the Ministry of Environment's 1982 report, *Lakefill Quality Study: Leslie Street Spit* acknowledges, "originally the quality of fill materials was not of concern and, at the earliest stages of the lake filling, the materials were comprised mostly of excavated earth, construction rubble, dredge spoils and miscellaneous solid waste" (MOE 1982, 4). The same year, a study was conducted to determine the anticipated availability and suitability of various materials for lakefilling activities. This investigation determined that excavated material from building sites and building rubble which contains only a small quantity of combustible material was the most suitable fill material (McLean 1982, 47). The report concluded further that controlled deposition of refuse, hydro ash (both bottom and fly) as well as material dredged from the bottom of the lake and river mouths were suitable. Digested sewage sludge was also considered suitable, if mixed with lean fill and applied as a cover material (McLean 1982, 48). Because almost anything was permitted as "fill", it was considered a limitless resource. Thinking big because of this abundance, the 1972 Waterfront Plan proposed a new set of large islands landfills, offering a set of new harbours (ibid).

However, by 1970, the Conservation Authority, sensitized to potential health and environmental concerns, declared that only clean fill-material excavated from construction sites and rubble – was suitable for use in the lake (ibid). This refined definition also limited the possible sources of fill and subsequently a more carefully considered set of proposals for land development. With this new definition, lakefilling could be seen as an experimental constructed landscape, supporting complex ecosystems while strengthening the lake's edge.

Taking both wave energy and erosion into account, lake edge construction relied on the segregation of materials by size and shape. A typical section of fill placement on an "armored edge" positioned large concrete pieces at the outer edge of the landform. This would protect small to medium sized concrete, brick rubble and broken asphalt which in turn would protect "core" excavated materials of dry clean earth, clay, silt and shale (Environmental Applications Group Ltd 1988, 39). As an example of this shift in attention, Schopf and Foster's analysis of the 1980 zone of the Leslie Street Spit reveals a "uniform and organized" material, containing no household artifacts (Schopf & Foster 2013, 10). Notably distinct from the 1964 zone, Schopf and Foster observe the intentional and strategic ecological restoration efforts to create habitats for birds, fish and other wildlife (ibid).

At the end of each case study in the 1988 report *Evaluation of Lakefilling Activity in Lake Ontario* concludes by stating, "In 1975, the Metropolitan Toronto and Region Conservation Authority (MTRCA) initiated a monitoring program as part of their Waterfront Development Policy, to determine the environmental effects of infilling selected areas of the lakeshore. The program was developed in compliance with the

Environmental Assessment Act, 1975" (Environmental Applications Group 1988, 54). While demonstrating a commitment to monitoring, the report doesn't provide any findings from the 13 years since of data collection. Nonetheless, the report provides a more detailed set of chemical criteria for determining the acceptability of its status as fill. Strict parameters outline maximum quantities of mercury, PCBs, lead, cadmium, phosphorus and arsenic measured in parts per million. Fill containing copper, zinc, nitrogen, chromium, iron, nickel, cobalt, silver, cyanide and ammonia were to be assessed on a case-by-case basis (Environmental Applications Group Ltd 1988, 132).

Read on a granular scale, we observe parallel shifts in perceptions of "fill" and the material itself. As regulations tightened, definitions became more precise and public awareness rose, and the shoreline also became uniform and standardized. Recognition that the potentially contaminating fill warranted greater scrutiny and revealed the broader implications of lakefilling practices on both human and ecological communities. At the same time this changing material was used to construct landscapes that were designed to express changing ideas *about* the landscape: from dump to modern exhibition to ecological park for public engagement with nature.

5 CONCLUSION

In this paper, we explore the intrinsic relationships between construction and demolition activities. Situated in post-war Toronto, this story is told at three scales: through urban planning schemes, the shifting tools and techniques of its demolition industry, and changing attitudes towards "fill" material. Connecting the destruction of its urban landscape with the creation of new shorelines, this study reveals the nuanced and networked relationships which define these activities. Throughout these dynamics, we chart the rise of rational modern principles and the swell of public engagement that followed. Drawing attention to these processes, we observe how demands for transparency and accountability resulted in reorganization at all three scales.

Ephemeral and erased, the history of demolition is written before-and-after the conventional focus of construction history. But the history of demolition is right under our feet: a new ground on which more construction has already occurred. Articulating a need for critical histories of the relationship between urban development and demolition, this paper offers a contribution to nascent research on Toronto's demolition history and opens new paths of inquiry into construction. From here we may ask: how can the study of demolition reveal otherwise invisible dimensions of our landscapes and the processes which shape them? What potential biases and implications might we discover? How might we translate this new knowledge into more culturally and environmentally sustainable practices in the future?

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Thematic session: Hypar concrete shells. A structural, geometric and constructive revolution in the mid-20th century

History of Construction Cultures – Mascarenhas-Mateus & Paula Pires (eds)

Juan Antonio Tonda, hyperbolic paraboloid builder

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ABSTRACT: Two works by the Spanish-born Mexican architect Juan Antonio Tonda Magallón are presented. They date from the period 1962 to 1975. He collaborated in the first of these works as structural consultant with the architect Alberto González Pozo, while he was the architect of the second work. Tonda was educated with Félix Candela, working in Cubiertas Ala. He started by analysing shell structures and participating in works direction. Although he was always in contact with Candela, he soon started to execute his own projects. Both of the works presented here employ original solutions using hyperbolic paraboloids. In the first he proposes a new arrangement of several sections of the paraboloid to form a portal in an opening which he covers with spans measuring from 11.0 m to 16.40 m. In the second solution, he proposes an alternative constructive system to using scaffolding and wooden shuttering, which he replaces by a spatial structure in rolled steel.

1 INTRODUCTION

At the age of 22, and without having completed his architecture studies, Juan Antonio Tonda (1931–20016) began to work with Félix Candela (1910–1997). It was 1953 and the company Cubiertas Ala S.A. had been created by Candela and the architects Fernando and Raúl Fernández Rangel in 1950 (Del Cueto 2011). Tonda finished his studies in 1962 with an exercise entitled “In search of a new expression in Architecture, with application to an Apartment Building” which, although it did not use shell structures, the author attributes its origin to Candela’s “revolutionary spirit” (Figure 1). He continued to collaborate with him until Candela left Mexico in 1971, and even years later, in 1978, they participated in a project in Saudi Arabia and Paris, working together for one year (Tonda 2010).

Tonda’s professional activity was influenced by his relationship with Candela. He began by collaborating with him but, little by little, began to concentrate on his own projects. In many cases as architect and in others as a structural consultant in projects by other architects, such as Alberto González Pozo. On the other hand, Tonda started work as Candela’s assistant professor at the Architecture Faculty of the Universidad Nacional Autónoma de México (UNAM). He always taught, joining the Faculty of Architecture as a professor. According to Tonda himself, in 25 years he executed shell projects for 32 churches, 5 petrol stations, 5 industrial buildings, 2 commercial establishments, 33 bungalows and 1 market. Of all these works, we are going to present two that stand out for being original contributions by Tonda. One is the Church of San Antonio de Padua in Xotepingo, Mexico City. This project was by the architects Alberto González Pozo and Leonardo Vilchis Platas, with whom Tonda collaborated as a structural consultant. The other is the Church of María Madre de Cristo in Iztapalapa, also in México City. This is a project by Tonda with the collaboration of the architect José Luis Rincón. The latter was also a collaborator and successor of Tonda in the UNAM Faculty of Architecture. The first project dates from 1963 and the second from 1972.

As a result of his teaching work, he published a text on the analysis of reinforced concrete shells (Tonda 1973) in which, among other aspects, he explains how to analyse what he calls short cylindrical sheets. This is the same procedure he deploys for the project of the cylindrical vaults and supporting arches of an expansion to the Bacardí México bottling plant carried out in 1971 (Martínez 2018a, b) and in a warehouse for Bodegas Pedrages in Mexico City in 1967, both still in use today.

Another result of his teaching and professional links was the publication of a manual for the analysis of hyperbolic paraboloids, accompanied by nomograms that facilitate the calculation and verification of these structures (Tonda & Tonda 1972).

2 SAN ANTONIO DE PADUA

The San Antonio de Padua church was a project by the architects Alberto González Pozo and Leonardo

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Figure 1. Juan Antonio Tonda's undergraduate thesis to obtain the title of architect. Perspective and elevation of a housing project (Del Cueto 2014; Tonda 2009).

Figure 2. Original proposal for the church of San Antonio de Padua. The skylight in the central section of the roof sections can be seen here but was never built. Nor is the apse the same as that built (Alberto González Pozo Archive in A. A. M.)

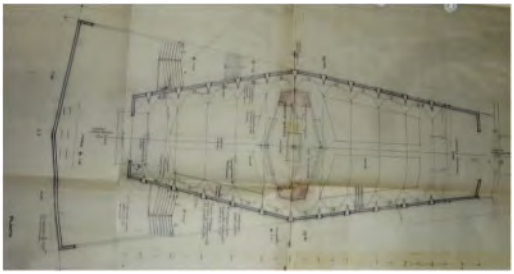

Figure 3. Plan of the proposed church with the straight chancel and an open atrium (Alberto González Pozo Archive in A.A.M.).

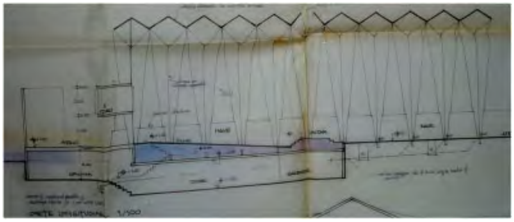

Figure 4. Cross section of the proposal with a straight chancel. The raised choir in front of the atrium is visible (Alberto González Pozo Archive in A. A. M.).

Vilchis Platas. Although several preliminary projects were prepared, and even Candela made a proposal that we have not located, both architects, with Tonda as structural consultant, finally drew up an original solution for the building.

One of the conditions the project had to fulfil was that it could be carried out in phases, each of which would be executed only when the parish made the necessary funds available. The promoter of the work lacked the necessary capital to undertake the work in one phase so its organisation into parts was indispensable. In fact, the church began construction in 1963 and was completed in 1980. For the bell tower project, separate from the church, a proposal from March 1977 is preserved, and with its decoration based on ceramic pieces not completed until 1993. In this work, in addition to his work as a structural consultant, Tonda also worked as a builder.

The building is located on a long narrow plot between División del Norte and Madroño streets in Xotepingo, Mexico City. It displays a rhomboidal floorplan so that its width increases from the entrance towards the centre of the church and falls again towards the apse. The latter has a semi-circular plan to form an ambulatory. The church structure is organized on the basis of 3.0 m wide sections with different spans. Each section consists of two supports and a beam, all made up of pairs of sections with ruled surfaces. Each section is independent of the following. In fact, this quality made it possible to organize the construction in phases, which were completed as funds became available. The roof of the original project included a skylight located in the central section, the one with the greatest span but this was never built. In total, it is made up of 11 sections organized symmetrically, one central and five on each side. The central section has a 16.40 m span and the ends 11.0 m spans (Figure 2).

At least three proposals were studied for the chancel. The first (Figures 2, 3) is resolved with a symmetrical solution in which the chancel takes on the same shape as the entrance. The choir would be elevated in the chancel and the altar located in the church centre. The whole building would be made up of only eleven symmetrical sections (Figures 3, 4).

In another of the options studied, the church ends with six roof elements similar to those of the frames that form the building, but using only half of them. They are arranged in a semicircle, so that the ends of the roof coincide in a common vertex. This vertex is above the roof, leaving a skylight to illuminate the altar (Figure 5). The finally built option is a variant of the previous. This uses six elements arranged radially, composed of supports made with a ruled surface like those of the church's sections. The roofs of these six elements coincide at a point located at the height of the end of the supports, 13.40 m. At the chancel end, the

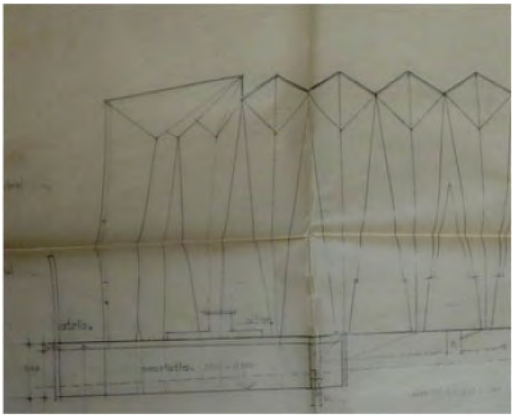

Figure 5. Longitudinal section of the chancel formed by six elements arranged radially with the roof above the hall, making it possible to install a skylight (Alberto González Pozo Archive in A. A. M.).

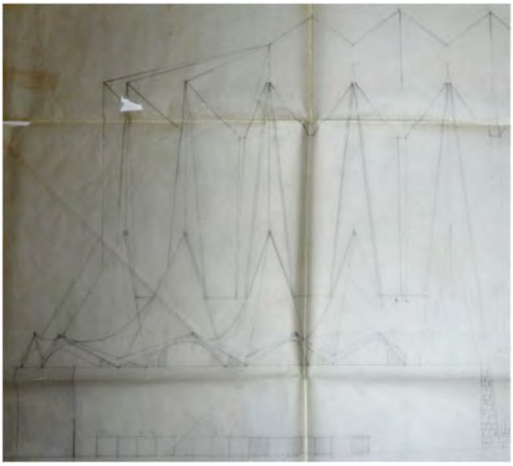

Figure 6. Apse formed by six sections of roof and nine sections of paraboloid over the ambulatory (Alberto González Pozo Archive in A. A. M.).

nave is completed with nine radially arranged sections of hyperbolic paraboloid (Figures 6, 7, 9).

Each section of the roof comprises four paraboloids arranged symmetrically. The supports are composed of two ruled surfaces. At the start, there are two 120 mm thick shells that form an angle of about 22° between them and that occupy a length of 1.0 m transversal to the building and 0.50 m in the longitudinal direction.

These pieces are opened and elongated towards the upper end, where they occupy the total width of the 3.00 m section. Transversally, they occupy a length of 2.00 m in the centre. Due to the increase in span of the sections towards the centre of the church, in one of the support ruled surfaces the plan length is 2.25 m and 1.75 m in the other. The highest vertex of the support shells is 13.40 m high in all sections so that the height of the building roof is constant throughout its length.

Figure 7. Visible outside the hyperbolic paraboloids of the chancel are the hyperbolic paraboloid that form the pillars of the cover and the radially arranged hyperbolic paraboloid (Image by the authors).

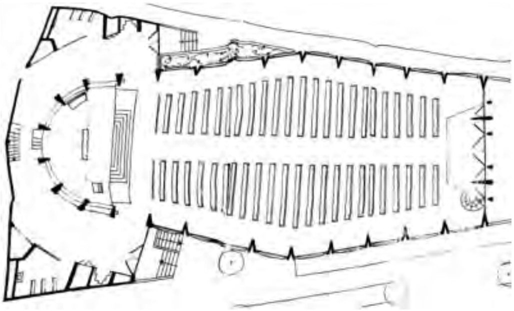

Figure 8. Floorplan of the solution as finally built. The eleven pairs of supports of the frames and the six pillars that form the apse can be seen (Alberto González Pozo Archive in the A.A.M.)

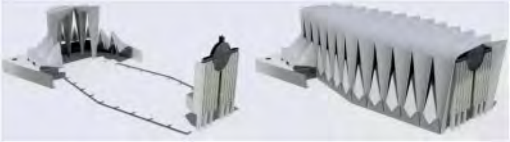

Figure 9. Church roof arrangement. Left show the radial disposition of pillars and hyperbolic paraboloid that cover the chancel and the façade structure. Right the disposition of the twelve elements that form the roof (Image Moisés Escárcega).

Each of the shells that form the support starts at the same height above the foundation, and their topmost points reach the said height of 13.40 m, while the ends of the interior edges end at a height of 11.40 m. In this way, all the supports end in two inclined edges on which the roof sections rest (Figures 8, 9, 10).

The roof sections are organized so that the edges that join the external vertices of the supports are horizontal and are at a height of 13.40 m. The edge that joins the lowest points of the supports is inclined. It starts at an elevation of 11.40 m and rises in the centre to 14.05 m, 0.65 m above the upper end of the supports.

Tonda had made hyperbolic paraboloids arranged in an umbrella shape in the way popularized by Candela, and which Cubiertas Ala used in more than

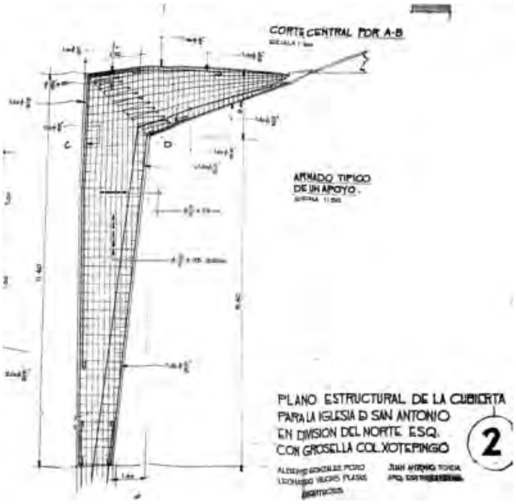

Figure 10. Elevation of the support with detailed drawing of the reinforcement. The upper left corner coincides with the horizontal edge of the roof ruled surfaces. (Alberto González Pozo Archive in the A.A.M.).

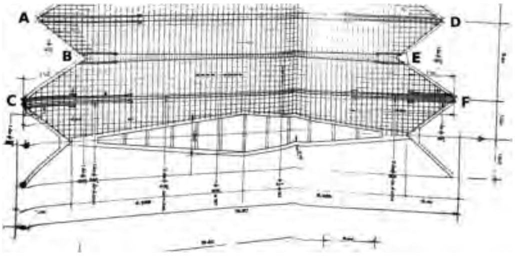

Figure 11. Plan of two sections of the San Antonio de Padua church roof. The central and one adjacent section are shown. The unmade skylight can be seen in the central section (Alberto González Pozo Archive in the A.A.M.).

Figure 12. Exterior of the building showing the arrangement of the supports for the different sections. They consist of two ruled surfaces that increase in width from bottom to top (Image of the authors).

Figure 13. View of the Church with the supports and roof visible (Image of the authors.).

eight hundred works. He also made roofs with juxtaposed paraboloid sections like that used by Candela in the Altillo Chapel, and groin vaults formed by the intersection of several paraboloids, such as the Los Manantiales de Xochimilco restaurant project. However, Xotepingo church architecture is an original creation of Tonda and González Pozo. Using eight sections of paraboloid, it forms a frame with two supports and a beam. The width of the beam is 3.0 m of the section itself. The supports expand their width from the base to the roof, allowing glazed openings in the facade (Figure 12).

The portico lintel is formed by four sections of paraboloid that rest on the ends of the supports. The lintel is 3.00 m wide. Figure 11 displays the plan of two modules. One is the central section with the skylight that was never completed. Each section of roof rests on edges ABC and DEF. Vertices A, C, D and F are at elevation 13.40 m and B and E are 2 m lower. The edges that join A and D and C and F appear horizontal in the project plans, and the one that connects B with F starts at elevation 11.40 m and reaches 14.05 m in the centre. (Figures 10, 11).

This can be understood as a variable depth frame; at the ends the lintel is 2.0 m deep and in the centre of the span 0.65 m. The start of the supports is 1.00 m deep. The sections of ruled surface on the roof are 60 mm thick so their own weight can be considered as 1.5 kN/m^2. A slenderness of 275 is assumed for a span of 16.40 m. In the supports, the width of the ruled surfaces is a constant 120 mm.

As indicated, although Félix Candela proposed an initial solution for this church, it was not built. Likewise, the architects were in contact with Cubiertas Ala during the project as they thought they would build it. However, the proposed solution was original and different from usual practice in the company.

Indeed, there is a letter signed by Candela in which he states that, after studying the project, “he finds serious difficulties for its general stability…” and so declares that they will not be able to carry out the work (Figure 13).

Candela here becomes like a builder facing work for which he has no previous experience and so prefers not to get involved.

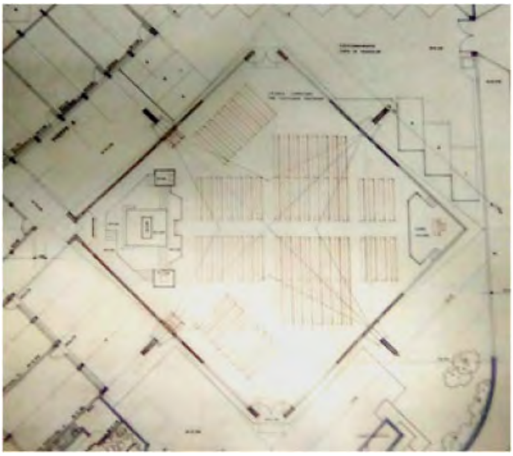

Figure 14. Plan of María Madre de Cristo Church. The four supports can be seen on the sides of the floorplan (Juan Antonio Tonda Archive in the A.A.M.)

Finally, Juan Antonio Tonda took charge of building in addition to defining the structure of the work.

3 MARÍA MADRE DE CRISTO CHURCH

María Madre de Cristo Church is a project by Juan Antonio Tonda in which the architect José Luis Rincón collaborated. It is located in Iztapalapa, Mexico City and built in 1977. The nave of the church has a square plan with 20.0 m sides (Figure 14). There are doors into the church on three of the four sides, while in the fourth wall a window illuminates the altar from behind. In the centre of each face and around the perimeter of the church reinforced concrete supports are located on which the roof rests (Figures 14, 16). The roof structure comprises four sections of hyperbolic paraboloid that are only joined at the supporting vertices in the reinforced concrete supports, leaving a space between them that is covered by a skylight (Figures 15, 17)

The originality of this work lies in the construction technique used. In an interview, Tonda remembered that he had designed several churches for the same entity. In all cases, the lack of money meant a limitation on the realization of new works. After several roofs had been made with reinforced concrete shells, they realized that the cost of the formwork was a very important proportion of the total cost and so asked Tonda if it could be eliminated. Tonda's response to this suggestion represents an important contribution.

However, as far as we know, the resulting solution was not repeated on more occasions. In the aforementioned interview, Tonda recalls that a locksmith made the complete metal structure on which the roof was cast.

The procedure devised by Tonda consisted of making a permanent formwork based on a steel structure. A three-dimensional lattice was built that would act as a support for the formwork, on which the concrete of the shell was poured. The steel bars were left in place. Each section of hyperbolic paraboloid was built using 15 straight generatrices in each direction and a family of diagonals was placed between the vertices of each resulting quadrangular section. The arrangement

Figure 15. Interior of the church. The two paraboloid sections join only at the concrete support (Image Moisés Escárcega).

Figure 16. Exterior of the church. The support is the only point where the paraboloid sections meet (Image Moisés Escárcega).

Figure 17. View of the bars forming the cover (Image Moisés Escárcega).

of these diagonals follows the shape of the parabolas, with the concave side up.

The use of bar structures to support the formwork on which the concrete of the shell is placed lies in the origin of shell construction. The first domes made in Germany in the 1920s used a single-layer steel bar structure. The formwork was supported on it and the concrete was sprayed on. The steel bars served as reinforcement and domes with thicknesses of around 60 mm could be created (Schönemann 1987).

The procedure used by Tonda is similar, with the difference that the metal framework that supports the formwork is not included in the concrete shell.

In order to reduce the impact of the formwork and scaffolding on the construction of concrete shells, alternative solutions were studied very early on. In 1948, Torroja made such a proposal for an industrial warehouse (Antuña 2020, AET). Although unbuilt, he made and tested a reduced model of a cylindrical barrel vault composed of a single layer of steel bars. It was not built but, years later, this solution was used to build the test hall of the Instituto Técnico de la Construcción y el Cemento (Azorín et al. 2012). Makowski would start travelling the same path ten years later, in 1955 (Makowski 1985).

In 1976, Tonda analysed a solution for the church's roof. The results of the matrix analysis of a three-dimensional bar structure archived under this name are preserved. It was carried out in the calculation centre of UNAM by the program's author, Julio Damy, using a "program for the analysis of three-dimensional reinforcements, with a maximum of 1400 knots and 5300 bars." A symmetry condition was used for a single layer and only half of one of the paraboloid sections was simulated, a total of 120 nodes and 315 bars.

Two sections were taken for the definition of the bars; "4-inch channel" and "¾-inch rod". The results of stresses and tensions in the bars coincide with a section of 287 mm^2, which corresponds to a circular section of that diameter. This bar was used throughout the deck. The 4-inch channel was used at the perimeter of each paraboloid element.

This verification testifies to the capacity of the steel structure to support its own weight during the concreting of the roof.

4 DISCUSSION

Both of these works by Juan Antonio Tonda were original solutions that were not continued for developing their possibilities. Although Candela's scepticism remains valid for the first work, this is not the case for his opinion that the structure was not viable. This may be viewed as proof of the difficulty of introducing modifications into previously established industrial processes. Indeed, Cubiertas Ala specialized in a very precise construction procedure. But modifications, such as the new arrangement proposed by Tonda, required dedication and effort that undoubtedly reduced or even ruled out the possibility of economic gain.

Tonda demonstrates the stability of the whole structure. To achieve this, he studies a support subjected to wind action acting transversely to the building. It checks stability and resistance by analysing the support as fixed at the base, without considering continuity with the cover. The situation of the structure with the two supports joined by the lintel seems equally safe. The situation where only one of the sections is subjected to horizontal action in the longitudinal direction may be more compromising. Nevertheless, stability would be assured as soon as more than one of the sections had been built.

As for the second project, the innovation of eliminating the scaffolding leads, at least in theory, to a notable saving, although how much greatly depends on place and time. It would be necessary to compare the cost of erecting around 4,000 kg of steel compared to placing about 10 m^3 of wood in formwork boards. Obviously, the decision is conditioned by a large number of factors, and it is impossible to generalize. However, Tonda made the remarkable and original contribution of the scope for making hyperbolic paraboloid structures more economically. As an alternative to the proposed procedure, the steel framework could be used to support the formwork and functioning simultaneously by reinforcing the concrete, and this might be subject to study.

5 CONCLUSIONS

Two works by the architect Juan Antonio Tonda are presented in this text.

With what he learned from Félix Candela and the experience accumulated during his time at Cubundas Ala, Juan Antonio Tonda continued exploring new paths in shell construction; his design ability and technical skill are evident in both the works analysed. As part of his academic work, Tonda was the founder and professor of the postgraduate Specialization in Light Roof Design at the UNAM Faculty of Architecture.

The true legacy of a teacher is manifested in the works of his disciples, when they assimilate and reinterpret the virtues of their mentor and then take their own course. At Roofs Wing, Tonda also absorbed the teachings of Antonio Candela, a great builder and the brother of Félix. From them, he learned the philosophy of making structures resistant due to their shape, the possibilities offered in this field by use of the hyperbolic paraboloid, and the way to design, calculate and build shells without Candela and also to introduce new shapes and new procedures to build this kind of roof.

He also managed, on the one hand, to develop original ways of combining paraboloids, giving rise to formally different structures, such as that of San Antonio de Padua. On the other hand, his experience as a builder allowed him to devise original construction techniques that expanded the scope for making this type of roof.

However, he failed to make new construction techniques competitive. As an employee during the 20 years prior to the construction of the church of María Madre de Dios, he had taken part in the construction of some of the more than eight hundred buildings made in Cubiertas Ala. More than 40 industrial buildings built using this system are still standing today on the Vallejo Industrial estate, Mexico City, totalling more than 1,000 reinforced concrete umbrellas.

6 FUTURE WORK

Both building described are still in use and in good condition. They have overcome the effects of two major earthquakes in 1985 and in 2017. A detailed inspection would be necessary to describe the state of both buildings. In particular, it would be very useful to describe the condition of the reinforcements to be able to evaluate the safety of the structure.

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Félix Candela and the auditorium shell of the Maracaibo Country Club, Venezuela: A dual structural story

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ABSTRACT: This paper aims to highlight three aspects: i) the historical process involved in the design of the shell (never built) for the Auditorium of the Maracaibo Country Club in Venezuela (AMCC); ii) the analysis of the geometrical and structural evolution of the project; and iii) the significance of the AMCC in Candela's timeline of work concerning hyperbolic paraboloids shells.

1 INTRODUCTION

The Venezuela of the 1960s was a society with a firm vocation for modernization despite persisting inequalities. It was a society that had entered not only its peak in world oil production, but also a stage of accelerated professionalization steering public institutions and a flourishing practice of architecture and urbanism that accompanied a new emerging professional class crying out for new social spaces such as recreational clubs and professional associations.

One of these social spaces in particular, the Playa Azul Beach Club in Naiguatá (1955–1958), a recreational beach and maritime club, required Felix Candela to create a particular kind of covering (concrete shells). This would lead Candela to embark on a long series of projects and achievements in Venezuela, the second country to concentrate a number of Candela's designs and works after Mexico.

Candela was called on once again for the project for the Auditorium of the Maracaibo Country Club (AMCC) (1959–1962) in Zulia State (known as the oil state) – and in the country's second largest city – not only because of his previous design for the Playa Azul Beach Club but also because he had already been engaged in Maracaibo.

The Headquarters and Auditorium of the Medical Association Center of Zulia State (1962–1963), and the later Auditorium of the Venezuelan Center of Engineers (1962–1965), were among other projects and works Félix Candela had also carried out with his company Cubiertas Ala de Venezuela in association with local architects Miguel Casas Armengol and Álvaro Coto Asenjo, the latter the Venezuelan representative of that company.

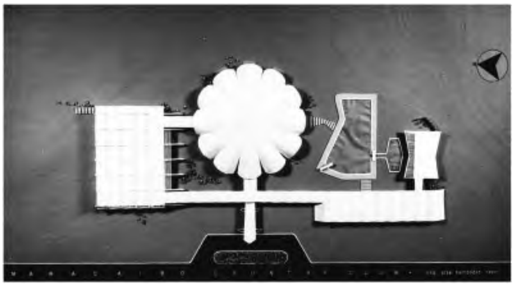

Figure 1. Auditorium of the Maracaibo Country Club. Proposal by architect José Hernández Casas. Maracaibo, Venezuela (Source: José Hernández Casas Archives, project promotional brochure ca.1960).

The AMCC project required of Candela a roof (concrete shell) for a multiple use space (open auditorium, ballroom, sports courts, etc.), following the initial design by architect José Hernández Casas.

This paper firstly aims to examine correspondence concerning the project of the AMCC. Second, it will explore the AMCC project's structural evolution over time, from the initial drawings of architect José Hernández Casas (1959) (Figure 1) to the final drawings of Candela (1962), who modified the structural solution proposed by Hernández Casas. It will also review Candela's project for the AMCC in the context of his work on double curvature structures (hyperbolic paraboloids), in order to understand its historical significance and the challenges this work posed to him at that time.

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Finally, we will detail the main differences between both shell designs through a geometrical analysis emphasizing the structural evolution of this project, which was never built.

2 THE MARACAIBO COUNTRY CLUB AUDITORIUM PROJECT

2.1 *History of the project in correspondence*

In a letter dated 15 April 1962, architect Álvaro Coto Asenjo, legal representative of the firm Cubiertas Ala de Venezuela, a company owned by Félix Candela founded on 24 September 1959, refers to the AMCC project for the first time as follows:

"Architect Miguel Casas Armengol, is the Director of the School of Architecture of Zulia, and a man of great influence in the context; this architect is also the man who is pushing us the most to get us to enter a competition, starting from the initial project, in the realization of the University Campus of Zulia state. At the same time, he has the project of the Medical College of Maracaibo that has about 1500 m2 of umbrellas that I already calculated for him and an Auditorium of which I send you a copy for calculations (…)

Club de Maracaibo – Architect Hernández Casas: This gentleman is the Project Manager of the University Campus, and I am very interested in fitting in with him; together with Casas Armengol, they are the basic 'dumbbell' of this Project. How are the calculations going for this project?"

Candela responds to this letter 15 days later on 30 April 1962:

"Club de Maracaibo – Architect Hernández Casas: I have already finished the calculations some time ago, but I have not been able to make the drawings. I'm sending you a copy of a sketch so that you can show it to the Architect and see if he agrees; and I'll put the drawings in one of the copies so that you can make the estimate.

I will send you the details of the shape and the coordinates of the arches to be built later, if you are not able to do it there. Let me know if you need a definite version of the memorandum. Hopefully not, because it will be a bit tiresome to clear up my numbers".

Candela, before the previous paragraph, confesses to Coto the problems he is facing in the office with the drawings:

"I can't find any draftsmen because the ones who come from the University aren't used to this kind of work and they're no good to me. I hope to solve this problem in what's left of the week, and I ask of you to be patient".

This correspondence explains Candela's delaying with the AMCC drawings. The drawings of the "detail of the shape and the coordinates of the arches" are not in the Candela archives consulted (Avery Library of Columbia University, Felix & Dorothy Candela Archive Princeton University and Archivo Coto Asenjo of the Coto Villarroel family).

After these two letters, no further letters are recorded in the Candela archives at Columbia University concerning the AMCC project.

2.2 *The two structural projects for the AMCC*

The preliminary planimetric project (dated 13 June 1959) sent by Hernández Casas to Álvaro Coto was forwarded by the latter to Félix Candela on 15 April 1962, almost three years later, a period of time from which there is no concrete information on any other correspondence in the archives consulted (Columbia University, Princeton University and Álvaro Coto Asenjo Archive).

In any case, when Coto sent the letter to Candela on 15 April 1962, he asked: "How are the calculations being done on that piece", to which Candela replied on 30 April of the same year: "I have already finished the calculations some time ago, but I have not been able to do the drawings", thus confirming that there were written communications those dates, and from Candela's expression, we can assume that these seem to be communications from the year 1961.

The connection between the architect José Hernández Casas and Candela, through communications with the architect Álvaro Coto, was established by the architect Miguel Casas Armengol, a great modern architect from Maracaibo and founder of the School of Architecture of the Universidad del Zulia, who was very well connected in international modern architecture.

Casas Armengol had already invited Félix Candela to collaborate with him on two projects that would be executed in Maracaibo, both already mentioned at the beginning of this paper, and this was the reason why Candela was in Maracaibo in 1963. Casa Armengol had also already managed to bring Frei Otto to Maracaibo in 1962 and, later on, Richard Neutra, Buckminster Fuller and Curt Siegel, among others.

The non-implementation of the AMCC project was most likely due to budgetary or internal policy restrictions affecting the Maracaibo Country Club itself, although we have not been able to corroborate that claim.

3 GEOMETRY OF THE MARACAIBO COUNTRY CLUB

The geometry of the Maracaibo Country Club shows an evolution of the geometries previously put forward by Felix Candela. From his first experiment with the Cosmic Rays shell (1951) in Mexico City (Figure 2), to the crossing shells seen at the Botanical Garden Pavilion with three shells (1962) in Oslo (Figure 3) and the four shells of the old Mexican Stock Exchange (1953–1955), also in Mexico City (Figure 4), Candela then built five shells at Los Relojes dining room at the La Selva Hotel & Casino (1959–1960) in Cuernavaca (Figures 5–6), and eight shells rotating out from a center circle at Los Manantiales Restaurant (1958) (Figures 7–8). This evolution

Figure 2. Cosmic Rays shell, Ciudad Universitaria UNAM, Mexico, 1951. With Jorge González Reyna (Source: Acción Cultural Española 2012).

Figure 3. Botanical Garden Pavilion in Oslo, Norway, 1961 (Source: Candela 1985).

Figure 4. Mexican Stock Exchange, Mexico City, 1955. With Enrique de la Mora and Fernando López Carmona (Source: Faber 1963).

Figure 5. Los Relojes dining room of La Selva Hotel Casino, 1960, Cuernavaca, Mexico (Source: Faber 1963).

Figure 6. Los Relojes dining room, La Selva Hotel & Casino in Cuernavaca, Mexico, 1960 (Source: Isono/structurae.net 1994).

Figure 7. Los Manantiales Restaurant, Mexico City, 1958. With Joaquín Álvarez Ordóñez. (Source: Faber 1963).

Figure 8. Los Manantiales Restaurant, Mexico City, 1958. With Joaquín Álvarez Ordóñez (Source: Moreyra & Billington 2009).

culminated in Candela’s structural re-design of José Hernández Casas’s 12-shell design (Figures 9–10).

Although the geometry proposed by Hernández Casas is not the classic anticlastic geometry of a hyperbolic paraboloid that Felix Candela likes, in the proposal that Felix Candela returns to José Hernández

Figure 9. Design for the Maracaibo Country Club in Maracaibo, Venezuela. Architect José Hernández Casas (Source: José Hernández Casas Archives. Project promotional brochure, ca. 1960).

Casas, the adjustment to the geometry is clearly visible, using, in this case the hyperbolic paraboloids in the shell's design (Figure 9).

3.1 *Simulation of structural behavior.*

The process began with the analysis of the structural plans and architectural proposals of the two geometries, and the layout of the plan in Rhinoceros; afterwards the modeling of the surfaces of the shells was performed in 3D with Rhinoceros 6.

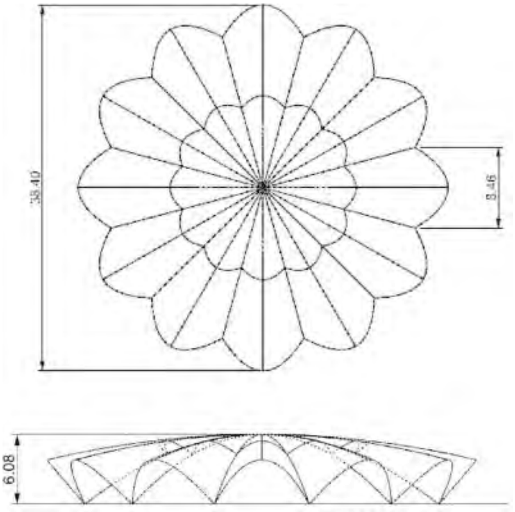
Finally, the structural behavior is simulated in the add-on Karamba 3D once the data from both proposals has been uploaded to Grasshopper (González & Di Marco 2018).

"Rhinoceros 6 can create, edit, analyze, document, render, animate, and translate NURBS curves, surfaces and solids, point clouds, and polygon meshes. There are no limits on complexity, degree, or size beyond those of your hardware. Grasshopper is a graphical algorithm editor tightly integrated with Rhino's 3D modeling tools. Karamba 3D is a parametric structural engineering tool, which provides accurate analysis of spatial trusses, frames and shells".

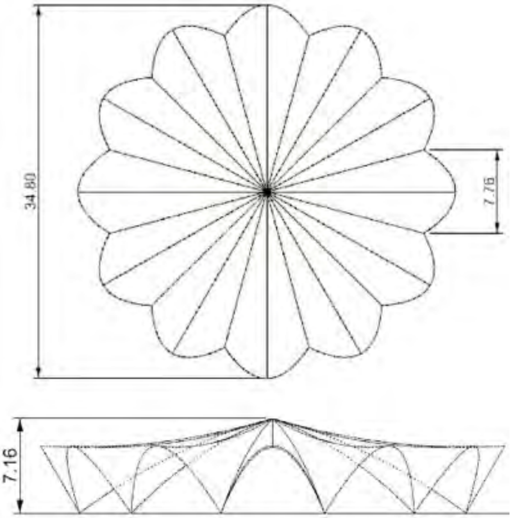
3.2 *Modeling of the concrete shells.*

The simulation of the structure in Grasshopper was facilitated by the modeling of the geometry in Rhinoceros using the Sweep 2 rails command. To develop one of the segments, only half of the paraboloid was used to form a surface that would cover half of one of the segments followed by use of the Mirror command.

Where one of the rails used forms a paraboloid that begins at the midpoint of the main paraboloid that will shape the shell, the rail ends at the center of the structure. The other rail is a straight line that starts at the end of the main parabola and ends at the center of the shell. A mirror command was applied in order to obtain the hyperbolic paraboloid of one of the shells.



PROPOSAL 1



PROPOSAL 2

Figure 10. Top: Proposal 1 José Hernández Casas. Bottom: Proposal 2 Félix Candela (Source: drawings of the Avery Library archive at Columbia University).

The structure was completed applying a polar array (Figure 11).

After the 3D modeling, the shells in Rhinoceros were imported to Grasshopper by means of a BREP container and later reparametrizing the geometry in Grasshopper. Then, the surface becomes a mesh, an important characteristic for the simulation of the structural behavior simulation with Karamba 3D.

In the modeling process, although the plans do not have the thickness of the shell, it was decided to work the simulation with a thickness of 4 cm, similar to the

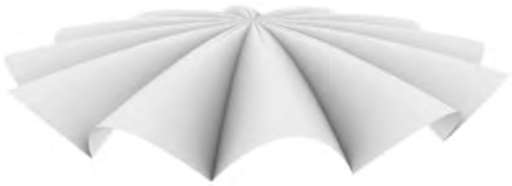


Figure 11. 3D shells modeling. Top: José Hernández Casas's design. Bottom: Felix Candela's design.

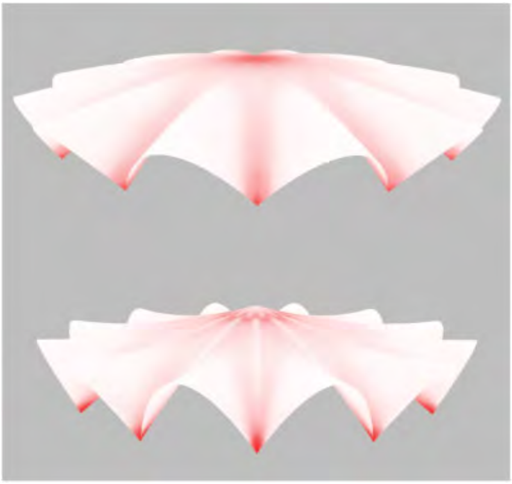


Figure 12. Axial forces. Top: José Hernández Casas's proposal. Bottom: Felix Candela's proposal.

structural specifications of the restaurant Los Manantiales in Xochimilco and the concrete shell of the Engineers Center in Maracaibo (Gonzalez et al. 2019).

3.3 *Structural simulation with Karamba 3D.*

Once the 3D modeling of the structures was done, each of the geometries was converted into structural elements, in this case into meshes. Later the model was structurally analyzed in Karamba 3D. For the data collection, the thickness of both concrete shells in the simulation of the structural behavior was 4 cm thick.

In both proposals, minimum displacements are observed no bigger than 1 cm. The proposal optimized by Candela was the one with fewer deformations. The biggest difference was observed in the weight: Candela's optimized shell is 20 t lighter but the weight per square meter is similar: the proposal by Hernández Casas could weigh 99.95 kg per square meter whereas the proposal by Candela could weigh 100.16 kg per square meter.

Table 1. Displacements and weight of both proposals. (4 cm thickness)

	Maximum displacement (cm)	Mass (kg)
Shell proposal 1	0.1279	138135.35
Shell proposal 2	0.1143	118098.54

In the simulation of the shells, a greater concentration of axial stresses is not observed; the joining of the hyperbolic paraboloids stabilizes the shells. In Proposal 1, greater compressive stresses are observed in the center of the shell, while in Proposal 2, greater compressive stresses are generated in the supports (Figure 12, Table 1).

4 CONCLUSIONS

Candela's project for the AMCC has not been previously considered in other studies, yet it represents a footprint in the historical line of his work on double-curved shells: a single piece with the largest number of hyperbolic paraboloids.

There is a lack of evidence to complete the correspondence and graphic history linked to the project for the AMCC in Venezuela; nevertheless, as revealed in this paper, proof exists in the form of letters and forceful drawings that allow us to confirm the existence of at least two projects: one by architect José Hernández Casas and another by Candela, based on the first project proposed by the former, and proposed to Cubiertas Ala de Venezuela for calculation.

In fact, this never-completed project contains two structural proposals within it: the initial one characterized by a structural geometry of 12 parabolic "arches" and the final one, Candela's design, with a structure featuring 12 "arches" but of double curvature, composed of hyperbolic paraboloids.

This structural change proposed and calculated by Candela relates this work with his previous designs, but increasing the number of shells to go from the single shell of the Cosmic Rays Pavilion (1951), to the eight shells of the Manantiales Restaurant (1958) – later replicated in Valencia, Spain (Oceanographer 1991–2002) – and culminating in the 12 shells of the AMCC in Venezuela that make the design unique in Candela's work for this type of structure.

In this regard, it is worth quoting Ignacio del Cueto who reminds us that, in a lecture given in 1954, Candela maintained: "the originality of a correct structure is always ephemeral. Once a structural type is successful, its repetition is inevitable, since among the conditions of that success must be, economy, efficiency and ease of execution”. However, we can affirm that Candela never repeated himself, but rather developed inspired variations on the same theme” (2011).

Finally, it should be noted that, after Mexico, Venezuela is the country where Felix Candela’s impulse materialized in the largest number of projects and works with hyperbolic parabolic structures.

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Thanks to the Avery Library of Columbia University (Drawings and Archives), the Princeton University (Félix & Dorothy Candela Archive) and the Coto Villarroel family (Coto Asenjo Archive), for allowing us to consult their respective archives.

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History of Construction Cultures – Mascarenhas-Mateus & Paula Pires (eds)

The design and construction of Marcel Breuer's Hunter College Library hypars: Their origin and influences

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ABSTRACT: During the summer of 1955, Eduardo Catalano went to work for a short period of time at Marcel Breuer's office in New York City. During that summer, Breuer's office was working on several projects, including a new railroad station in New London, Connecticut (unbuilt) and the Hunter College Library, Classroom, and Administration Buildings in the Bronx, New York (built between 1957–60). In these two projects, there is a clear evidence of Catalano's influence and knowledge of thin reinforced concrete shells and the use of hypars, in structures. This paper explores how the friendship and collaboration of these two architects, Breuer and Catalano, allowed Breuer to introduce the use of hyperbolic paraboloid concrete shells and ruled surfaces in several important projects like the Library at Hunter College and, later, in the Chapel of the Annunciation Priory of the Sisters of St. Benedict in Bismarck, North Dakota, USA and in the Church of Saint Francis de Sales, among others.

1 INTRODUCTION

During the summer of 1955, the Argentinian architect Eduardo Catalano went to work for a short period of time at Marcel Breuer's office in New York City, after Catalano built his house in Raleigh, North Carolina in 1954 with a hyperbolic paraboloid roof that impressed Breuer (Gatje 2000, 61). Breuer and Catalano had an extended friendship, since Catalano graduated with his second master's degree in Architecture in 1945 at Harvard University, where Breuer was teaching under the direction of Walter Gropius. The relationship between Breuer and Catalano was continuously nurtured by contacts and correspondence. Breuer was invited by Catalano during the summer of 1947 to lecture at the Universidad de Buenos Aires, Universidad de Tucuman and the Sociedad Central de Arquitectos, which appointed Breuer as an honorary member. While in Buenos Aires, Catalano and his architecture partner, Carlos Coire, asked Breuer to collaborate with them on the design of the Ariston Club in Mar de Plata, a dining and dancing facility on Playa Serena, built between 1947–48 and published in the magazine, *Architectural Record*, just after its inauguration (Breuer 1984). The Ariston Club was Marcel Breuer's first experience had using reinforced concrete for structural elements, since steel and timber were more common in the United States at that time. The Ariston Club consists of a two-story curvilinear shape with four leaves floating above columns. The building inherited the form of a previous Breuer design for a cafe included in the proposal for a competition, The Garden City of the Future. The building was designed in collaboration with F.R.S. York, in London in 1936, and comprised a curvilinear shape made of three leaves instead of four with three stories floating above the columns. After this collaboration, Breuer recommended Catalano for scholarship to teach at the Architectural Association in London from 1950 to 1951 (Breuer 1949); he also wrote a letter recommending Catalano to Henry Kamphoefner, Dean of the School of Design at North Carolina State College, for a professor position in 1951 (Breuer 1951). Starting in 1952, Catalano continued the school's exploration in architecture, structure and construction started by Matthew Novicki, a Polish architect, Head of the Department of Architecture and designer of the Dorton Arena in Raleigh, North Carolina. This structure was formed by a saddle-shaped roof suspended from parabolic concrete arches. Catalano, inspired by Novicki's work, established a research program to study the use of hyperbolic paraboloid structural surfaces to cover greater areas with the least material, work which was published in 1960 as *Structures of Warped Surfaces: Combinations of Units of Hyperbolic Paraboloids*, by the Students Publications of the School of Design (Catalano 1960), where he expanded the formal studies of hyperbolic paraboloids initiated by Lafaille and Aimond and continued by Candela. Felix Candela was regularly invited by Catalano to lecture at the School of Design at North Carolina State College and both were important figures in disseminating information about the use of hyperbolic paraboloid structures in the post-World War II period in the USA.

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2 FIRST HYPARS DESIGNED AT BREUER'S OFFICE

Between leaving the School of Design at North Carolina State College and teaching in the graduate program at MIT in Cambridge, Massachusetts, Eduardo Catalano joined Breuer's office for a short period of time during in summer of 1955. At that time, Breuer was working on several projects, including a new railroad station in New London, Connecticut (unbuilt) and the Hunter College Library, Classroom and Administration Buildings in the Bronx, New York (1957–60). In these two projects, there is a clear evidence of Catalano's influence and knowledge of thin reinforced concrete shells and the use of hypars in structures. Breuer was an admirer of Catalano's house in Raleigh, North Carolina, and he wrote him just after the house was completed, saying, "I am very anxious to see your 62'-0" span. It sounds exciting" (Breuer 1954). The abandoned house, demolished in 2001, featured a 4,000 square foot hyperbolic paraboloid roof built of three layers of 3" × ¾" wood planks placed in alternative directions with a total thickness of 2.5" that was supported at just two points, without using reinforced concrete, and framed by a perimeter steel profile (*A New Way to Span Space*, 1955).

Several sketches dated 1955 related to the study of the hyperbolic paraboloid shape and its development can be seen in the Breuer archives at Syracuse University. The sketches seem to depict the hypar of Catalano's house, with two low points labeled with an L and two high points labeled with an H.

It is also possible to find several versions of the design of the new railroad station in New London, Connecticut featuring hyperbolic paraboloids for the first time in a Breuer project, a clear indication of the influence of Eduardo Catalano during that summer (Calvo 2015). Early studies of the project to resolve a 320 × 160' roof can be seen in the drawing, "Concrete Shell: Solution No. 1 – Horizontal Edge". This shows the roof divided into eight squares with four different solutions using a thin shell structure, of which the last two represent the use of hypars. The first version of the project shows five aligned inverted umbrellas supported by central cruciform columns to support the roof and cover all the enclosed and outdoor spaces (Figure 1). In this version, the inverted umbrellas at the ends were tilted and asymmetric, as in Felix Candela's project for Rio's Warehouse, in Linda Vista, Mexico City, built in 1954. This was one of the first projects designed and built by Felix Candela featuring this type of shell structure (Faber 1963), which Eduardo Catalano probably knew about from his own studies and investigations in North Carolina. During 1954 and 1955, Felix Candela and his construction company, Cubiertas Ala, built several projects using the inverted umbrella typology roofs, such as in the High Life Textile Factory in Coyoacan, Mexico (1954–55) where the shells are also sloped in a sawtooth profile; the Acabados Finos factory in Puente de Vigas, State of Mexico, (1954–55); or the dock for La Tolteca Cement Works in Vallejo D.F. (1955) (Joedickr 1963).

In a second version of the project for this new railroad station designed by Breuer's firm, four inverted umbrellas are shown. Those at the ends remained tilted and asymmetric as in the previous version of five. Several studies and sketches show variations in adapting the roof to the floor plan and site, as well studies of both the umbrella and inverted umbrella typologies (Figure 2).

The final version of the project shows the roof area for the railroad station reduced to 200' × 50' and the solution of four symmetric inverted umbrellas supported by cruciform columns at the center. Sections also show that the outside surface of the hypars are planed smooth, so the water will drain towards an inlet and a drainage pipe, located at the center of each of the columns, while the reinforcement at the junction of the four hypars that the inverted umbrella create is marked by beams sticking out on the interior side of the roof that connect with each of the arms of each of the cruciform columns. A presentation set of plans was ready in August 1955, and a model was built of this final version that included a small inverted umbrella pavilion at the other side of the platform covering the ramp that crosses the railroad tracks underneath, connecting the parking and the station (Figure 3). This project was not built, but it was published by *Architectural Forum* in June of 1956.

The construction of the inverted umbrellas consists of a reinforced concrete shell based on the composition of four hyperbolic paraboloids, bounded by straight lines with the lower point of them at the center, where

Figure 1. First version for the design for the new railroad station in New London, Connecticut, USA, 1955. Marcel Breuer Digital Archives.

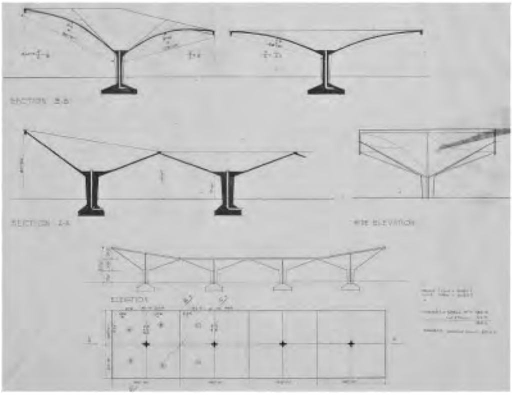

Figure 2. Study of inverted umbrellas for the design for a new railroad Station at New London, Connecticut, USA, 1955. Marcel Breuer Digital Archives.

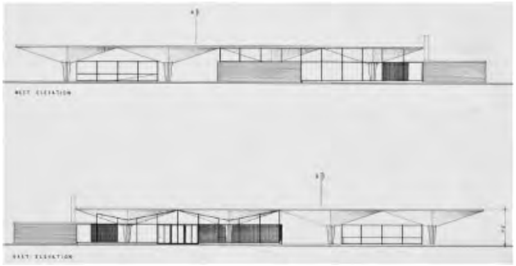

Figure 3. Final version of the design for a new railroad station in New London, Connecticut, USA, 1955. Marcel Breuer Digital Archives.

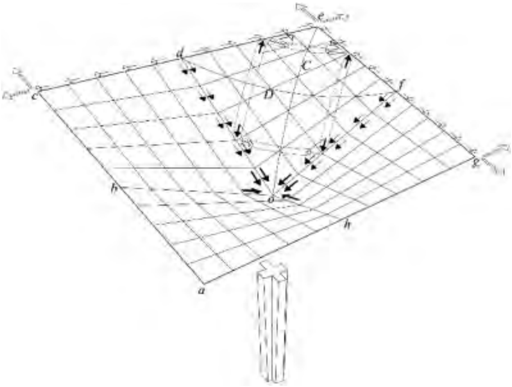

Figure 4. Structural behavior of an inverted umbrella.

the column stands. All sections parallel to the vertical plane d-f as seen in the image below, produce upward curving parabolas, and those parallel to the vertical plane o-e produce downward curving parabolas. The forces along the straight lines where the hypars meet are in compression under symmetrical loading, and greater than those along the edges that are tensile stresses. The compression in the valleys is solved by stiffener ribs with additions of steel reinforcement extending straight from the edge to the central lower point to meet the column. The tensile stress condition of the edges is very convenient, because, under even loading, they can be thinner than compression members (Joedickr 1963) (Figure 4).

The stiffener beams at the intersections of the hypars can be placed on the external or the internal face of the shell. Felix Candela's construction of inverted umbrellas shows the location of the reinforcement for the stiffener beams in the external face, favoring a continuous and more simple formwork, due to the continuous interior surface making it easier to build the formwork, and resulting in a smooth interior finish.

3 FIRST INVERTED UMBRELLAS BUILT IN THE USA

Hyperbolic paraboloids in architecture were relatively unknown in the USA prior to 1950. In Mexico, Felix Candela with his construction company, Cubiertas Ala, built his first experimental umbrella with reinforced concrete in Tecamachalco, in 1952, a square, inverted umbrella shaped by four 10 × 10-meter hypar tympans rising 1 meter from the center. The roof shell was 4 centimeters thick and supported by a central column (Candela, 1955, 397–416). After that, Candela not only designed and built numerous buildings featuring hypar umbrellas in Mexico, he also was invited to lecture at many universities in the United States during the '50s. He also participated in important events that promoted the use of thin shell structures like the Conference on Thin Concrete Shells at MIT held in June 1954, published in the *Journal of the American Concrete Institute*, and he also was a consultant for several American architects in the design of hypar structures.

One of the first attempts to build inverted-umbrella structures in the USA was for the Great Southwest Corporation (GSC), founded by Angus Wynne, who showed interest in the use of this type of shell structures for buildings in his 5,000-acre industrial district between Arlington and Dallas, Texas. They hired Candela as a consultant, and a first inverted umbrella was built as a test in December 1956 for the GSC in Denver, Colorado (Giral 2011). Candela was also recruited by Richard Colley and O'Neil Ford Architects in December 1956 for his participation in a competition to design the new Texas Instruments semiconductor plant in North Dallas. Their design, which featured a roof system of 63' × 63' inverted umbrellas to cover the upper level of the industrial building was selected. The first phase of construction was completed in 1958 (George 1992).

In 1957, John V. Christiansen, a structural engineer based in Seattle, Washington and an admirer of Candela's work, (Sprague 2013) designed and built his first hyperbolic paraboloid inverted umbrellas to cover the walkways of the Pioneer Middle School in Wenatchee, Washington. Then Christiansen became interested in the design of reusable formwork for building hyperbolic paraboloid umbrellas in order to be more cost-effective, and in developing a construction process to minimize labor. In July 1958, the American magazine, *Architectural Forum*, published "The Rise of Thin Shells" by Lawrence Lessing, featuring numerous projects using reinforced thin concrete shells in the United States, including the so-called "Mushroom Shells", inverted hyperbolic paraboloids placed edge to edge on columns, to form a small parochial school in Etna, Pennsylvania, designed by the engineers Triggs & Mellett (Lessing 1958).

4 THE INVERTED UMBRELLAS AT HUNTER COLLEGE LIBRARY BUILDING

In July 1955, the New York City Board of Higher Education commissioned Breuer to design both a new classroom/administration building and a library building for the Hunter College campus in the Bronx, New York. Robert Gatje was the associate architect named

Figure 5. Perspective rendering of the project for Hunter College, Bronx, New York, USA, 1955. Marcel Breuer Digital Archives.

at Breuer's firm and Eduardo Catalano acted as consultant while he was working at Breuer's office during that summer (Hyman 2001, 197). The classroom and administration building was completed in the fall of 1959 and the library in the summer of 1960. Both buildings were designed as independent structures connected by an 'entry link'. The administration and classrooms building was designed as a three-story 178' square around a central courtyard, while the library was a rectangle of 120' wide × 180' long. The project was selected for the "America Builds" exhibit in Berlin in 1957, sponsored by Breuer's friend, Peter Blake, and was showcased by a model of both buildings (Figure 5).

The 120' wide × 180' long library building is divided into a 2 × 3 grid of 60' × 60' squares, each of them covered by a 3.5" thick reinforced concrete shell, shaped as inverted umbrellas made of four hypars each, bounded by the higher straight sides and supported at the center by a cruciform column. The type of inverted umbrellas used in the Hunter College Library building are similar, but larger, than the ones designed for a new railroad station in New London. The space is completely enclosed by a glass curtain wall with external sun-shading provided by terra-cotta open block screens in the southeast and southwest facades (Figure 6).

Robert Gatje reported in his book that by the time Eduardo Catalano left for Cambridge, Massachusetts to teach in the graduate program at MIT in the fall of 1955, the library building was essentially designed (Gatje 2000, 64). The working drawings were completed a year later, and by April 1957, the structural engineers, Farkas & Barron, completed the development of the structure including the inverted umbrellas for the library roof. Because no one in the Building Department of New York City had knowledge of hyperbolic paraboloid or shell structures, the supervision of the structure for the library was assigned to a professor at Columbia who was also a member of the New York structural engineering fraternity, Mario Salvadori, who reviewed and approved the design plans and calculations (Gatje 2000, 65).

The library building featured a lower floor partially below grade containing the archives and library stacks, and an elevated main floor with the main reading room. This main floor exhibited the exposed inverted umbrella roofs in the ceiling from which a grid of lightweight rectangular metal tubes with the fluorescent lighting fixtures was hung, and through which the structure of the inverted umbrella roofs was clearly visible. The building is no longer a library as it was renovated and now houses the Art Department and Art Gallery of Lehman College. The inverted umbrellas of the roof are each supported by a cruciform column from which the stiffener beams are visible in the interior, instead of being placed on the exterior face. It creates a smooth and continuous surface in the exterior of the roof and shows the four different hypar shells of each umbrella from the interior. This is one of the main differences of the Hunter College Library's inverted umbrellas with those built by Felix Candela. The fact of projecting the stiffener beams towards the interior of the shell makes the formwork of each module more complex, but makes the view of the roof from the outside more uniform, which was visible from several buildings around it including the attached administration and classroom building.

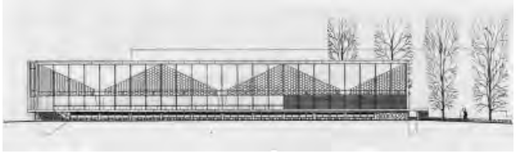

Figure 6. Northeast elevation of the library building for Hunter College, Bronx, New York, USA, 1955. Marcel Breuer Digital Archives.

The interior surface of the hypars was intentionally designed by Marcel Breuer to show off the shapes created by this type of construction system and adapted the formwork to use full-size plywood sheets. The interior ribbed pattern of each hypar is created by placing 2' × 8' plywood sheets from the edge to the stiffener beam and spacing them 3-1/8 inches at the edges and 4-1/2 inches at the beams to absorb the difference in length between both because the beam is inclined toward the top of the column. The design of the cruciform columns is also intentional as each of the arms of the column follows the direction of the stiffener beams as a continuous entity, which reduces its section towards the edge of the umbrella.

The builder was Leon D. DeMatteis Sons Inc., a construction company who had specialized in low-cost housing for the New York City Housing Department, but with no experience in the sophisticated construction systems at that time or the frequent visits to the construction site that this project would require (Gatje 2000, 65). The process of construction of the six inverted umbrellas can be seen in numerous images in the Breuer Archives. They show that the construction of the library's roof started in September 1958 and was completed in December of the same year. The six inverted umbrellas were built progressively, starting from the one at the western corner, then the

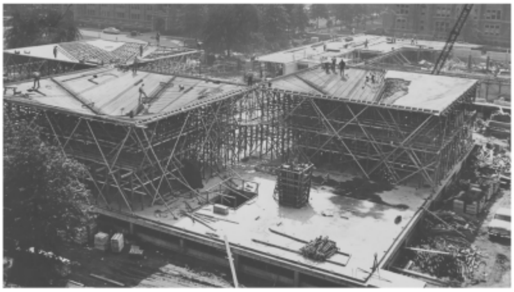

Figure 7. Construction process of the inverted umbrellas for the roof of the library building for Hunter College, Bronx, New York, USA, 1958. Marcel Breuer Digital Archives.

Figure 8. Construction process of the inverted umbrellas for the roof of the library building for the Hunter College, Bronx, New York, USA, 1958. Wire Reinforcement Institute.

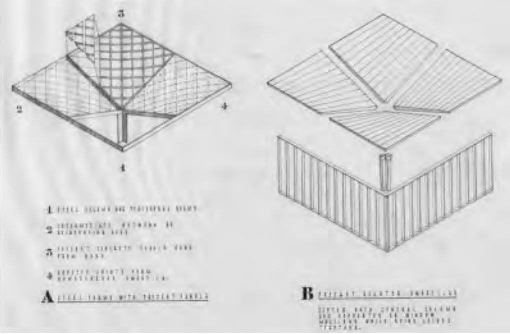

Figure 9. Interior of the inverted umbrellas of the library building for Hunter College, Bronx, New York, USA. 1958. Marcel Breuer Digital Archive.

one at the center in the northeast facade opposed to the administrative building, followed by the one at the south corner. The selection of these first three umbrellas to be built, located in a staggered position on the roof plan, allowed for more open space on the construction site due to the density of the shoring work. The images also show how each of them were in a different construction stage at the same time – the first one had all the reinforcing steel placed and waiting for the concrete to be poured while the second had its formwork completed, and the third had just the shoring system in place with some of the main supporting members of the formwork. It was not until the concrete of all three of them was cured that they started the construction of the three other inverted umbrellas (Figure 7).

Each inverted umbrella received twelve 700-pound mats of welded wire fabric reinforcement (over 4 tons of reinforcing). Each mat, 31-ft long and 10.5-ft wide, was lapped and 'nested' to the adjacent one. Reinforcement was designated 6 × 6 – 5-0/5-0, five ought gauge wires on 6-inch centers. The reinforced concrete slab was 3.5-inches thick. (Figure 8).

The uniqueness of the design of these inverted umbrellas relies on its internal surface. The cruciform column arms transformed into the stiffener beams, showing clearly how the forces travel from the hypar shells to the ground, and the ribbed pattern of the formwork shows how the double curvature of the surface is built from a series of straight lines.

Breuer was highly interested in the interior view of the structure above from the reading room, and ordered to remove one of every two fluorescent tubes of the lighting grid suspended from the ceiling to lower the lighting levels in the reading room which was so intense that it blinded the users if they tried to see the ceiling structure (Gatje 2000, 67) (Figure 9).

5 OTHER HYPERBOLIC PARABOLOIDS DESIGNED BY BREUER

Marcel Breuer made use of the hyperbolic paraboloid shapes several times after the design of the Hunter College Library. In 1957, while the Hunter College construction drawings were being completed by the Farkas & Barron engineers, at Breuer's office was developing several versions of the design of the Van Leer Office Building at Amstelveen in The Netherlands. One of the three versions for that project features a rectangular volume of about 40 × 80 m, divided into eight square modules of about 20 × 20 m each and organized in a 2 × 4 grid. Each square module was covered by an inverted umbrella roof supported by a cruciform column in the center of the module, similarly to the Hunter College Library, although this version was not selected to be built. The main difference between the Hunter College Library umbrellas and those in the Presentation drawings of this version of the Van Leer Office Building is that each inverted umbrellas was to be made out of a steel frame, column and peripheral beams, and an intermediate network of reinforcing bars with precast concrete panels hung from those bars, with the joints finally grouted to create a homogeneous umbrella roof (Figure 10). This system of precast concrete panels on a steel frame to build hyperbolic paraboloid shapes, was later used by

Figure 10. Proposed pre-fab, inverted umbrellas for the Van Leer Office Building, Amstelveen, Netherlands, 1957. Marcel Breuer Digital Archive.

Figure 11. Perspective rendering of the Ustivov House, 1959. Marcel Breuer Digital Archive.

Le Corbusier to build the Philips Pavilion at the World's Fair Expo '58 in Brussels.

5.1 *The design of the Ustinov house*

In the fall of 1959, Breuer began designing a house for the actor and director, Peter Ustinov, in Montreux, Switzerland. The design was completed by December of that year, showing a central rectangular volume that houses the living room and kitchen, while the bedrooms and a guest house are separate volumes following Breuer's binuclear concept. A pair of saddle hyperbolic paraboloid shells create the roof over the living room and kitchen supported by three buttresses or 'shoes' on the ground. The rectangular area covered by this roof is formed by two 12-m squares with each square being the projection of the hypars above (Figure 11). A similar design was developed by Candela in 1958 for a Beach Club in Playa Azul, Venezuela in collaboration with the architects Guillermo Shelley and Jose Chavez. The structural drawings for the reinforced concrete roof of the Ustinov House were developed by Weisenfeld, Hayward & Leon Consulting Engineers of New York, and completed in May 1960. A design adaptation of the Ustinov House was built in 1973 as the Saier House in Glanville, France.

Figure 12. Interior of the hypars on the Main Church of the Annunciation Priory, Bismarck, North Dakota, USA, 1962. Marcel Breuer Digital Archive.

5.2 *The roof for the Annunciation Priory*

The project for a Priory for the Benedictine Sisters of the Annunciation in Bismarck, North Dakota was developed by Breuer's office in two phases. The first phase, built between 1958 and 1959, included a dormitory wing, classrooms, communal facilities and a small chapel. The design of the second phase was developed in 1960 and built between 1961 and 1962. This second phase included the convent wing and the main church. The roof for the main church of the convent is formed by one 'hipped or gable' roof in the center with halves attached to the entrance and altar side, with the columns-buttresses in the lateral facades and joined at their high edges along the central long axis of the church, creating a free column interior. The roof hypars of the church have an interior ribbed pattern created with the formwork like the one was used in the Hunter College Library by placing separated 2' × 8' plywood sheets from the exterior sloped edged to the horizontal roof top (Figure 12). The construction of the church's roof began in May of 1962 and was finally completed in August. Images of the construction process shows how the first hypars built were the two by the altar, followed by the others in a progressive sequence moving towards the entrance of the church from the courtyard (Figure 13).

5.3 *The Church of St. Francis de Sales*

In 1961, before the roof structure of the Annunciation Priory was completed, Breuer was working on

Figure 13. Construction process of the roof on the main church of the Annunciation Priory, Bismarck, North Dakota, USA, 1962. Marcel Breuer Digital Archive.

Figure 14. Church of St. Francis de Sales, Muskegon, Michigan, USA, 1966. Marcel Breuer Digital Archive.

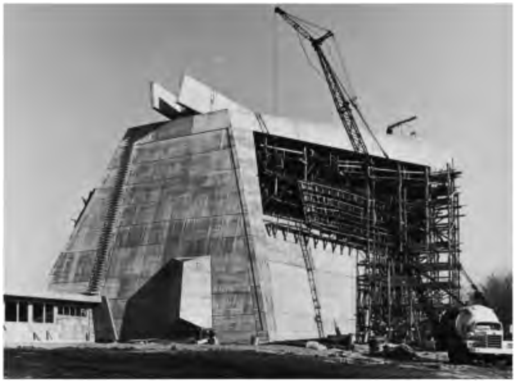

Figure 15. Construction process of lateral hyperbolic paraboloid. Church of St. Francis de Sales, Muskegon, Michigan, USA, 1966. Marcel Breuer Digital Archive.

the design of a Catholic parish church in Muskegon, Michigan (Figure 14). Breuer's associate, Robert Gatje, recalls in his book how, after discussing several solutions for the structural shape of the church with Paul Weidlinger, the consulting engineer for this project, Breuer came into the office with a sketch with the geometrical solution based upon side walls in the shape of hyperbolic paraboloids (Gatje 2000, 120), which was the final design solution to enclose the space, although those lateral walls are not structural (Figure 15). The construction of the church and refectory of St. Francis de Sales started in 1964 and was completed in 1966. A similar design with the lateral walls in the form of hyperbolic paraboloids was later adopted by Breuer in the auditorium of the Tri-Arts Center for Cardinal Stritch College in Milwaukee, Wisconsin in 1965, a project that was not built.

6 CONCLUSIONS

The summer of 1955 that Eduardo Catalano spent at Breuer's office in New York, was a determining factor in arousing Marcel Breuer's interest in shell structures, specifically in the shape of hyperbolic paraboloids. Starting with the unbuilt project of the new railroad station in New London, Connecticut, and in building the inverted umbrella roof for the Hunter College Library, Breuer's interest in these types of structures lasted until the mid-1960s, with the exception of the construction of the Saier House in 1973 that followed the design for the unbuilt Ustinov House from 1959. Breuer's unique artistic formation at the Bauhaus and the strong influence that the Italian engineer, Pier Luigi Nervi, had on him prompted the use of these types of structures that influenced the form of his designs (Calvo 2018). Breuer also added special qualities to these inverted umbrellas, such as the ribbon patterns on the interior surfaces that show how the roofs were constructed using straight lines for the formwork.

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History of Construction Cultures – Mascarenhas-Mateus & Paula Pires (eds)

Replicating Candela's Los Manantiales

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ABSTRACT: The idiosyncratic 1958 thin shell roof of Los Manantiales restaurant in Xochimilco, south of Mexico City, designed by master Félix Candela, became a model often replicated during the following 50 years. The appearance of this futuristic shell was Candela's dream design, a seed planted in Mexico that then flourished across four continents. This replicating phenomenon is hereby studied chronologically through seven case studies. For each case study, the investigation briefly discusses the background behind its construction, gives a profile of its designers, explores similarities and differences in construction methods vis-a-vis those used in Xochimilco, and considers whether the structure subsequently acquired local or national prominence. During his lifetime, Candela was pleased that his ideas were adopted and developed by other practitioners, and lessons can be learned from Candela's work and from the sequels it inspired.

1 INTRODUCTION

What is so unique about the triumphal arches of Rome or the design of the Seagram Building in New York City that they became design models for countless constructions in many cultures? Do these archetypes embody the symbolic spirit or societal aspirations of their time and place? Like these monumental works, projects by master shell builder Félix Candela became so recognizable that the name Candela is synonymous with projects whose construction resemble his principles. Responsible for making the thin, concrete shell popular, and in particular the groundbreaking development of the hyperbolic paraboloid (hypar), an inverted umbrella form with four tympans, Candela is a signature name in modern architecture.

1.1 *Los Manantiales: Function, form, construction*

Candela's most famous project is Los Manantiales, a restaurant facing a lake basin canal in Xochimilco, south of Mexico City. Its roof shell was first developed for a project that did not come to fruition. However, the architects of record, Joaquín and Fernando Álvarez Ordóñez, and Candela, used the same concept to replace a burned down restaurant in Xochimilco. Built by Candela's firm, Cubiertas Ala, in 1957–1958, according to Candela's description "the shell over the main dining area is an octagonal, groined vault, formed by the intersection of four hyperbolic paraboloids. Edges of the shells were formed by cutting the surfaces in an outward-tilting plane" (*Progressive Architecture* 1959). Fernando Álvarez Ordóñez claims he personally ensured the groins were modeled upward to form an endless undulating surface. Los Manantiales is listed in the INBA catalog (Figures 1, 2).

Figure 1. Postcard of Los Manantiales, ca. 1960s (Eduardo Alarcón collection).

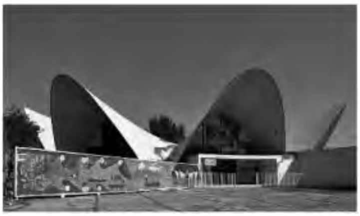

Figure 2. Today (photo by the author, 2020).

Notwithstanding its seemingly complex double curvature, constructing the roof shape was accomplished with straight-line pine board scaffoldings arrayed along the generatrix of the hypars alone. These wooden boards were fixed atop thousands of wooden uprights, ledgers, and stringers assembled in place by specialized carpenters. A reinforcing steel mesh topped the formwork and viscous concrete was poured by hand, one bucket at a time, by dozens of laborers. The wooden scaffoldings and formboards were removed when the concrete achieved its bearing weight capacity, leaving a shell resembling a giant clam or a flower with eight petals or segments.

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Figure 3. Panel from *Dennis visits Mexico* comic book, 1960. Courtesy of Aldo Solano Rojas.

Figure 4. Capture from *The Coming of Astro* episode of *The Jetsons*, 1962.

1.2 *Los Manantiales: Symbol of the future*

It took virtually no time for Los Manantiales to gain fame. Its swooping shell was reproduced in popular international publications such as the *Dennis the Menace visits Mexico* comic book (Ketcham 1960) (Figure 3) and LIFE Universal Library's *Mexico* book (1962). With Eero Saarinen's airport terminals and later Heinz Isler's ultra-thin shells, Félix Candela's unconventional works conveyed revolutionary possibilities. These architects were forecasting their collective dreams by means of their extraordinary concrete sculptures. Los Manantiales became a symbol of Mexican modern architecture and an image of future architecture. Hanna Barbera's comic sitcom, *The Jetsons*, routinely aired Candela-style shells floating in *Orbit City's* (Benedict 1962) (Figure 4).

According to Alan Hess, "you see this interest in these futuristic ideas not only in architecture or car design but in cartoons like *The Jetsons* and places like amusements parks like Disneyland's Tomorrowland – in advertisements, in magazines, and so forth, certainly in the movies as well" (Novak 2012).

Table 1. Candela's groined hypar vaults.

Building, Location-Country	Year	Segments
La Jacaranda Cabaret, Acapulco	1957	3
Los Manantiales, Xochimilco	1958	8
Casino de la Selva, Cuernavaca	1959	5
Centro Electrónico, Mexico City*	1960	10
Iglesia de la Florida, Mexico City	1963	8
L' Oceanogràfic, Valencia-Spain	2003	8

* Unbuilt

Figure 5. Iglesia de la Florida (photo by Eduardo Alarcón Azuela, 2012).

Figure 6. L'Oceanogràfic (photo by Concha de Rojas, 2020).

1.3 *Candela's variations of the groined hypar vault*

In 1954, Candela built his first groined hypar vault by developing the design by Enrique de la Mora and Fernando López Carmona for La Bolsa Mexicana de Valores (Mexican Stock Exchange) building in Mexico City, continuing to explore applications of the same constructive principle (see Table 1) (Figures 5, 6).

After 1958, Candela's buildings resembling Los Manantiales are considered "clones"; they bear all of Félix Candela's genetic makeup. L' Oceanogràfic, built six years after his death, was the last clone; its span diameter was 8% larger than the original, but more slimly proportioned. Its construction included recently developed concrete techniques with stainless steel and Dramix steel fibers (Domingo et al. 2002). The curtain walls have heavy mirror glass fenestration which interrupts the transparency of this posthumous homage to Candela in his home country.

1.4 *Spreading the news*

Starting in the early 1950s, international journals enthusiastically published articles written by or about

Table 2. Groined hypar vault replicates.

Building Location	Year	Segments
Mineral Water Pavilion Olanesti, Romania	1959–1960	3
La Concha Motel Las Vegas, Nevada, USA	1961	3
T. L. Osborn Headquarters Tulsa, Oklahoma-USA	1962 razed 2009	10
Sant Louis de Gonzague church Richibucto, Canada	1964–1965	12 of varying heights
San Pablo Apóstol church Guadalajara-Mexico	1971	8
Miguel Hidalgo Market Guadalajara, Mexico	1973	8 (separate hypars)

Candela. He presented at multiple conferences at influential universities such as MIT (1954), where he proposed a simplified thin shell calculation method. The *Journal of the American Concrete Institute, Progressive Architecture*, the French *L'architecture d'aujourd hui*, and Spanish *Arquitectura*, among others, were launching pads for the works of a man who proposed a practical and affordable technique. That technique resulted in forms that seem to emerge from nature, forms in which engineering and sculpture go hand in hand. In February 1959, two articles about Los Manantiales were published in *Progressive Architecture*, the architectural journal with the world's highest circulation at the time: "Recent Work of Mexico's Felix Candela: Restaurant Xochimilco" and "Can a Man Be Architect, Engineer, and Builder?" The latter states, "In his own opinion, Candela's restaurant structure at Xochimilco is probably his most significant work to date (…) the final result of one phase of structural investigation" (Holmes & Craighton 1959). Twelve drawings and images illustrate the finished shell without any discussion of the construction process. Did the thirteen-petal Covered Market (1955) in Royan-France, designed by René Sarger, anticipate the aesthetics of Los Manantiales? The ellipsoidal shell at La Concha Hotel (1958), in San Juan de Puerto Rico, takes formal clues from Sarger's project (Levy & Parnes 1961). Certainly, the *Progressive Architecture* articles led to a wealth of Los Manantiales-inspired reinterpretations (see Table 2).

Subsequently, other significant monthly magazines published on Candela: Spanish *Arquitectura* and Swiss *Bauen + Wohnen*. In the former, Rafael de la Hoz (1959) celebrates that Candela generously submitted construction drawings. The latter offers detailed construction specifications (*Bauen + Wohnen* 1961). Both magazines predate Colin Faber's canonic book, *Candela/The Shell Builder*, which displays full construction information and a beautiful perspective drawing that illustrates the way the shell derives from hyperbolic paraboloids formed by straight-lines (Faber 1963).

Undoubtedly, the iconic buildings' appearance has also been disseminated globally by non-academic publications such as postcards, postal stationary, tourist brochures and travel guides. Some media spread the designs more broadly and quickly than books, trade journals, or professional magazines.

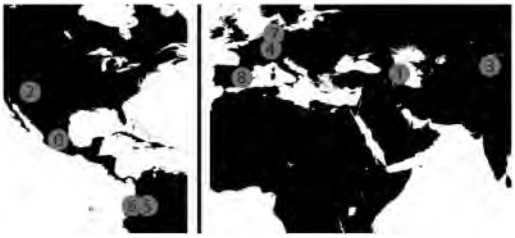

Figure 7. Locations: 0. Xochimilco, Mexico; 1. Baku, Azerbaijan; 2. Tucson, Arizona, USA; 3 Bishkek, Kyrgyz Republic; 4. Stuttgart, Germany; 5. Coca, Ecuador; 6. Esmeraldas, Ecuador; 7. Potsdam, GDR; 8. Valencia, Spain.

Figure 8. Zhemchuzhina (now Mirvari) Café, ca. 1962.

2 REPLICAS OF AN ARCHETYPE

Case studies

During the next five decades, Los Manantiales' shell was replicated in four continents. Some are well known, others more obscure. This paper brings them to light, concentrating on those that: contain a groined hypar vault formed by the intersection of four hyperbolic paraboloids; rest on eight supports; and contain an outwardly tilted lobe or segment configuration. One exception is the Harrenstein House, which has six lobes.

Each case study, introduced in chronological order, offers a short history about the circumstances of its commission, naming its designers, exploring similarities and differences in construction methods with respect to Xochimilco, and questioning if each case study acquired local or national prominence or symbolism. Illustrations of each project prioritize completed buildings, postal reproductions, works under construction and status pictures, some obtained ad hoc for this investigation (Figure 7).

2.1 *Mirvari Café in Baku-Republic of Azerbaijan*

The first replica of Los Manantiales was constructed in 1962 in Baku, capital of the Azerbaijan Soviet

Figure 9. USSR postal stationery, 1976.

Figure 10. Mirvari Café under construction, ca. 1960.

Figure 11. Today (photo by Sanan Aliyev 2020).

Socialist Republic, then a founding member country of the USSR (Figures 8, 9). Architects Vadim Shulgin, Roufat Sharifov, Anna Val, and Irena Orlova-Stroganova designed this shell for a commission from Mayor Alish Lemberansky – an important figure in Baku's modernity. Lemberansky learned about Candela's projects during a trip to Scandinavia (Bulanova 2015). Did the Mayor see the Botanical Garden (1962) in Oslo-Norway under construction? Perhaps he stumbled upon one of the previously-mentioned publications? Shulgin placed a small shell in a conspicuous location on Baku's boulevard facing the Caspian Sea (Figure 10). The Mirvari Café shell sits atop a square platform that originally rose three meters above ground. Construction photos show wood board uprights, horizontal stringers, and diagonal cross bracings which hold parallel parabolic wooden arches in place and upon which the formwork rests, as opposed to on hypar generatrix boards. The advantage of using parabolas is addressed in case study 2.6. Local architect Elchin Aliyev asserts that the concrete placement involved "two workers with one cement shotgun for three days". Gunite, or shotcrete technology, consists of a calibrated cement-sand-water mix; the mix is shot through a pressure hose to apply a dense concrete layer to the formwork.

Shulgin was known for his openness to world culture and detachment from ideological dogmas.

Figure 12. Harrenstein House (photo by Bill Sears 1966).

However, due to Soviet era political sensitivities, the project was attacked as an "imitation of bourgeois architecture" (Nasibov 2019) (Figures 11). Interestingly, a design idea that arose in a distant, developing country, Mexico, was perceived as representing foreign capitalism. Documenting its popularity, the US National Geographic Society published a travel book in all 15 Soviet Union republics and chose the Mirvari to represent Baku (McDowell & Conger 1977). Today, the building is listed as an architectural monument of Soviet Modernism and is protected by the State. Corroborating its modern character, the Baku Pearl was replicated one decade later in the Kyrghiz Soviet Socialist Republic (See 2.3). In his book, Yuri Lebedev speaks of both projects as Soviet developments of architectural bionics without mentioning Candela (Lebedev 1973).

2.2 *Harrenstein House in Tucson, Arizona, USA*

Located in Tucson, a US city 100 km north of the Mexican border, Harrenstein House (1962–1963), is the only residential building among the case studies presented here (Figure 12). Owner and designer Dr Howard P. Harrenstein was a professor who specialized in concrete structures and was instrumental in the development of hypar construction norms in the USA. Given its proximity to the Titan missile defense system during the Cold War, Tucson was a nuclear target. Harrenstein envisioned the house as an experiment on thin shells and nuclear fallout shelters. Originally conceived as an eight-petal arrangement with an open-to-the-sky central courtyard, to aim interior views to the surrounding desert landscape, the design switched to a six-segment display. According to the Tucson Historic Preservation Foundation application for Historic Landmark, "The geometric, one story plan creates intimate and expressive interior spaces while promoting a vision of tomorrow" (Clinco 2018). Each cantilevered lobe works as shading device as the window fenestration is recessed deep into the shell while the roof unloads its weight on brick columns.

Shulgin devised a noteworthy system of reusable formworks. Roof construction proceeded 1/6 section at a time with only one formwork assembly. The assembly was relocated 60° to the next section until the circle was completed. Construction images show wooden boards placed horizontally to create the formwork without following the generatrix of the hypar. Once the form and steel reinforcing were in place, concrete was poured manually with buckets.

Figure 13. Formwork placement (photos by Howard Harrenstein, 1962). Tucson Historic Preservation Foundation digital collection.

Figure 14. Formwork placement (photos by Howard Harrenstein, 1962). Tucson Historic Preservation Foundation digital collection.

Figure 15. Bermet Café, ca. 1971.

Figure 16. USSR postal stationery, ca. 1970s.

Figure 17. Today (photos by Alina Pugacheva 2020).

Harrenstein House (Figures 13, 14), first listed as a National Monument in 2018, stands out for its original reutilization of materials, its specialized craftsmanship, and as a representative civil defense response to the Cold War Atomic Era.

2.3 *Bermet Café in Bishkek, Kyrgyz Republic*

The 1971 Bermet Café (Figures 15, 16), meaning "pearl" in Kyrgyz, was built in Friendship Park in Frunze (now Bishkek) in the Union of Soviet Socialist Republics (USSR). Located on the steppes, the city has a centrally planned layout. In the 1960s, authorities developed the *Fifty Years of USSR Park.* A smaller portion of that open space was named Friendship Park. To build it, "in typical Soviet fashion, they [the people] had to work for it. Schoolchildren and workers were drafted into brigades of volunteers, clearing away rocks, carting in soil, and planting trees" (Dzhumagulov & Li 2019). The Bermet Café was not directly inspired by the shell in Xochimilco but by the structure in Baku. According to Besien Kariev, the project was a centrally planned construct without an apparent design architect. As a consequence, the design is rather prescriptive: it has the same one-storey-high platform and the same thin shell form and proportions as Baku. Built by the same regime as the Baku but a decade later, the Bermet Café is a second-generation replica that validates the significance of the edifice in Baku. Unlike Baku, the Bermet Café is fronted by a sculptural public stairway. Its angular lines, exposed concrete panels, and cantilevered slabs speak to a Constructivist style representative of the period when it was built.«

USSR postcards and postal stationary featuring the café demonstrate that the building acquired a certain prominence within Soviet Frunze. This conclusion is supported by a catalog sheet in the State List of Architectural Monuments, in which the building is registered since 2003, research provided by local professors Dzhumamedel Imankulov and Tatyana Filatova. Decades ago, the Bermet Café was a well-known element of urban life. Recently, however, significant portions of the public park were handed over to private hands and the remaining portions are ill maintained.

A local envoy, Alina Pugacheva, verified the poor condition of the building site. The trees are overgrown throughout the park, while the areas around the building have been disturbed by poorly planned additions, wooden shacks, and fences that seriously compromise its appearance. (Figures 17, 18).

Currently privately owned, the top floor was enclosed with opaque mirror glass walls that block the transparency under the shell. The café is currently a hookah lounge, open just a few days a year, and little

Figure 18. Today (photos by Alina Pugacheva 2020).

Figure 19. Postcard of Pavilion for the 1977 BUGA, ca. 1977.

has been done to procure adequate protection for this jewel of Soviet-period heritage.

2.4 *Pavilion for the Federal Garden Exhibition in Stuttgart, Germany*

The 1977 Federal Garden Exhibition, or Bundesgartenschau (BUGA 1977), took place on the lower grounds of the Kingdom of Württemberg palace gardens in Stuttgart and received seven million visitors.

Continuing a tradition of expanding city green spaces and open environments, BUGA 1977 consisted of a 44-hectare master plan with landscape architecture, lakes, parks, squares, pedestrian and vehicular bridges, extensive walkways, urban art sculptures, and permanent and temporary exhibition pavilions. The latter included this case study by prominent structural artists Jörg Schlaich and Rudolph Bergermann. This 200-spectator Pavilion (Figure 19) was developed as a structural experiment on lightweight shells. At that time, Schlaich was exploring the capabilities of glass fiber reinforced concrete (GRC). Aside from trials with the new composite material, the project required a form inherently resistant to buckling. This is where shape of Los Manantiales shell entered into play. Trials on lighter weights also contributed to off-site shell prefabrication in eight separate segments. Because the shell used GRC, its thickness was reduced to only 12 mm, i.e. it is thinner than an eggshell relative to its size. The temporary shell earned the reputation of being "the building with the thinnest concrete roof in the world" (ArchInform 2018) (Figures 20, 21).

Frei Otto criticized the Pavilion, calling it a blatant copy of Los Manantiales. Fortunately, Schlaich took advantage of Candela's 1977 stay in Europe. He invited Candela to join him to visit his Stuttgart Pavilion. An older Candela was so excited to see a German engineer developing his ideas that "climbing to the top of the shell, he jumped up and down to test its deflections" (Holgate 1997). The Pavilion was scheduled to be disassembled six months after the start of the exhibition. However, it was demolished only five years later, in 1982; because it was critically vandalized, the GRC was brittle and its shell was deformed.

Figure 20. Precast segments lifted by crane and assembled into position, ca. 1976.

Figure 21. Precast segments lifted by crane and assembled into position, ca. 1976.

Figure 22. Under construction and recently removed formwork (photos by Laercio Almeida 1980).

2.5 *Auditorio Amazonas Casino in Coca-Ecuador*

In the late 1970s, the Ecuadorian Army Corps of Engineers (CEE), a centralized office in charge of constructing all military compounds in this South American country, devised a plan to deploy a standard-type casino at all military bases. An officer's casino is a large event hall enjoyed by high-ranking military personnel. Finished ca.1980, the Auditorio Amazonas officers' casino at Brigade #19-Napo (Figures 22, 23) was erected on the north bank of the Napo River;

Figure 23. Under construction and recently removed formwork (photos by Laercio Almeida 1980).

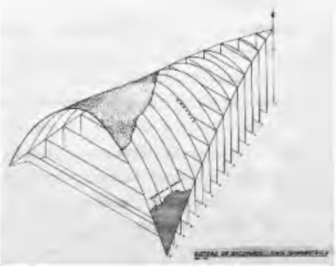

Figure 24. Drawing of parallel parabolic scaffoldings, 1978.

Figure 25. Today (photo by the author, 2017).

it lies in a remote Amazon tropical rainforest location, near the northern border with Colombia. Initially, the casino's roof was meant to be identical to the one in Xochimilco. The structural plans directly copy the drawings found in Faber's 1963 book. The engineering drawings, stored at CEE archives, were by engineer Juan B. González S. Remarkably, González's worthy contribution is evident in a unique construction process, different from the one used at Los Manantiales.

González created a system of wooden formwork, supported not by the straight-line generatrix of the hypar but by translation surface parabolas; the result is a series of parallel parabolic arches derived from cross-sectioning the lobes in vertical planes (Figure 24). Like case study 2.1 in Baku, the parabolas' sections were a product of geometric deductions at the drafting table; these resulted in simplified carpentry work tailored to non-specialized workmanship. Architectonically, the structure was only different from Xochimilco in that the architect, Hernando Parra, lifted the entire structure 1.82 m to prevent the hypar groins from discharging rainwater at ground level. As a result, potential drainage problems were eliminated and accessibility to the roof controlled. Site engineer-in-charge, Laercio Almeida, pointed out that the isolated location of the brigade suggested access and logistics difficulties. The scaffolding required enormous numbers of wooden poles and boards. (Figure 22). Resembling Candela's method, concrete placement was completed bucket by bucket; but here, pouring started at the summit of the hypars and finalized downwards at the groins.This shell, the largest curved free-edge shell in Ecuador, is the least known of the case studies still standing. It remained mostly unnoticed until a suspension bridge was built nearby in 2012. Recently, a request to have it registered in the Ecuadorian National Institute for Cultural Patrimony was submitted by the author.

Figure 26. Casino modification drawing, 1981.

2.6 *Montúfar Battalion Casino in Esmeraldas, Ecuador*

The BE-1 Montúfar Battalion officers' casino (ca.1981, Figure 26) was placed inside a military compound on a high mound overlooking the city of Esmeraldas. The battalion is located near the northern border with Colombia, close to the Pacific Ocean. Again, Juan González was the engineer of record. Upon its completion in the early 1980s, two Ecuadorian military precincts replicated the Xochimilco icon (Luzuriaga 2020). Unfortunately, the Montúfar casino was demolished between 1987 and 1989 after critical structural damage appeared, caused by seats on the structure's grounds. Because no known photographic records remain, it is impossible to compare it to Los Manantiales and draw conclusions about its foundational problems. No doubt, the unexpected demise of the Esmeraldas work contributed to the halting of subsequent construction of these standard-type casinos.

2.7 *Shore Pavilion Seerose in Potsdam, GDR*

The 1982–1983 Café Seerose, or "water lily", was built in a Stalinist-style, a high-rise, residential complex on the shore of Neustadt Havel Bay in Potsdam. When Ulrich Müther was commissioned with the project, he turned to a 1971 unbuilt Neubrandenburg kiosk based on Xochimilco. He owned the author's rights for that shell structure (Figures 27, 28), so he reused them, unaltered, for Potsdam (Ambrosius & Seebock 2016).

Figure 27. Scaffolding, 1982–1983. Müther Archive of Wismar University.

Figure 28. Potsdam-GDR postcard, ca.1985.

To avoid the appearance of political agendas, the International Association for Shell and Spatial Structures (IASS) held congresses in Eastern European cities, such as Leningrad and Bucharest. Matthias Ludwig asserts that, upon obtaining party authorizations, Müther attended some IASS meetings where he befriended Heinz Isler. No evidence indicates that Müther ever met Candela in person, but he could turn to the 1961 *Form und Bauweise der Schalen* by Manuel Sánchez-Arcas and to Faber's books. He admired Candela's figure to such an extent that his company logo was a variation on the San José Obrero church, seen in profile. Müther's accomplishments included using slim, available resources while still achieving the sense of wonder that only hypars inspire (Lammler & Wagner 2010). Müther was a rare entrepreneur, capable of leading his family-owned construction company under a controlling, socialist regime. Over three decades, he built over 70 standalone double curvature shells and developed projects in the GDR and overseas. Early GDR architecture was widely and favorably appraised; but it soon deteriorated into dull, prefabricated panel housing structures where aesthetics was of lesser importance. The country's political leadership saw in Müther's oeuvre a counterpoint to the at-best-average official architecture. With noteworthy commissions, his work blossomed. Margarete Fuchs's film *It's Up to You to Make It Swing* describes the role Müther played as builder of extraordinary facilities that beautifully fulfilled the material and cultural needs of the people (Fuchs 2002). The construction process was carried out by specialized manual workers using scaffoldings on steel pipes and telescopic nozzles as well as a wet gunite spray method. (Figures 29, 30). On the shell's top, a three-to-five-centimeter-thick expanded polystyrene insulation and two layers of roofing felt were put in place. The restaurant roof has a round opening in the apex for mechanical ventilation and a flatter inclination of the shell segments. Dieter Ahting, the architect, devised a functional distinction between supply wing, guest area, and terrace areas, thereby safeguarding the shell's transparency.

Figure 29. Gunite spraying, 1982–1983. Müther Archive of Wismar University.

Figure 30. Today (Frank Leipelt 2020).

The Seerose is considered the most exceptional Soviet period monument property in Potsdam. It was listed in 2004 under monument protection, separate from the surrounding complex within which it was originated.

3 DISCUSSION AND CONCLUSION

The idiosyncratic Los Manantiales became a dream design, a seed that was originally planted in Mexico and that then flourished in many other locations. Two of the case study replications disappeared. Functionally, three are food venues, three others are or were great halls, and one is a dwelling. Four were placed near a waterbody: a sea, a lake, or a river. However, their form was not a response to the context where they sit, since they are located randomly in steppes, deserts, or tropical rainforests. Figure 31 portrays geometric forms with top and front views.

Most structures are considerably smaller than Los Manantiales; one of the Ecuadorian structures has the same diameter and only Candela's L'Oceanogràfic is larger. All the structures have different proportions, petal inclinations, and architectural dynamism. Figure 31 and Table 3 compare supports span and outer

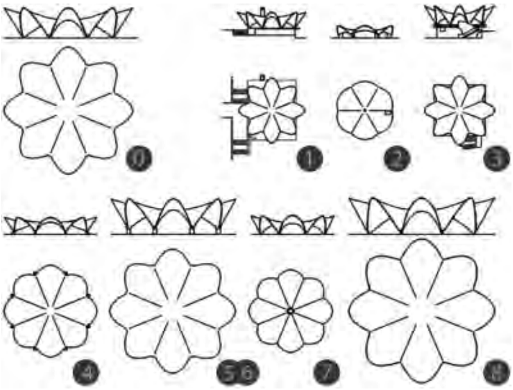

Figure 31. Case study comparison (See Table 3 for tag identification). Elaborated by the author, 2020.

Table 3. Comparative data on the case studies.

Building City-Country	Span ⊘ Outer ⊘ (m)	Shell High-Point (m)	Shell Thickness (cm)
0. Los Manantiales	32.47	9.93	4–5
Xochimilco, Mexico	42.43	9.93	
1. Mirvari Café	15.20*	5.46*	6–8
Baku, Azerbaijan	22.00*		
2. Harrenstein House	13.72	4.06	8*
Tucson, Arizona, USA	19.66*		
3. Bermet Café	15.72*	6.54*	10
Bishkek, Kyrgyz Republic	23.40*		
4. 1977 BUGA Pavilion	26.00	5.67	1.2
Stuttgart, Germany	31.00		
5. Auditorio Amazonas	32.47	11.14	8
Coca, Ecuador	42.00		
6. Montúfar Battalion	32.47*	11.14*	8*
Esmeraldas, Ecuador	42.00*		
7. Seerose Pavilion	23.00	6.23	6–7
Potsdam, GDR	28.00*		
8. L'Oceanogràfic	35.10	12.27	6
Valencia, Spain	48.73		

* Approximate dimension

lobe diameters, exterior highpoint and thickness of the shells. Together these figure and table establish differences in the shells' sizes and the slenderness of their proportions.

Construction methods vary significantly from one project to another: some use the same principles employed by Cubiertas Ala; some develop their own daring structural and construction techniques, e.g. off-site prefabrication, formwork reuse, variations on scaffolding design, use of gunite concrete applications, and cranes.

Like Xochimilco, the Baku and Potsdam shells retain a status of symbolizing modernity; unlike these, the one in Bishkek lost its former standing as city icon. However, most of the case study structures function well and are soundly maintained.

When Candela visited Stuttgart and viewed a project that reinterpreted his design concepts, he was not only delighted but also "with tears in his eyes he declared that he was gladdened to know his ideas were being passed on and developed in such a way" (Holgate 1997). We can only imagine how he would react if he knew that his masterpiece was reproduced so many times in so many places before his death, and we can learn much from Candela's projects, as well as from those he inspired.

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History of Construction Cultures – Mascarenhas-Mateus & Paula Pires (eds)

The collapse of the Tucker's gym: Research impulses in the USA at the end of hypar shells era

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ABSTRACT: Retracing the history of concrete hypar shells is to consider the events contributing to their progressive decline, notably during the 1970s. Despite it appearing to be a minor event, the sudden collapse of the Tucker High School gym (September 1970) influenced the research of the following years. It aroused a fervent de-bate among the most eminent engineers and academics of the USA, affiliated with the ACI Committee 334, regarding the accuracy of the calculation methods used. This paper aims to contribute to the description and discussion of the so-called last season of the thin concrete shell structures in the USA. Retracing the history of the gym project, the collapse, and consequent scientific impulse, the research highlights how the 70s was characterized by seminal scientific contributions, supported by the use of early software using the finite element numerical calculation.

1 INTRODUCTION

The diffusion of hyperbolic paraboloid (hypar) thin shells was an extraordinary experience in construction history of the 20th century. Equally remarkable is to investigate the events relating and contributing to their progressive decline. Over the last few years, many studies have been undertaken on the history of concrete thin shells, especially based on quadric geometries. In particular, they have focused on the early experiments, further developments, and their diffusion from Europe to North and South America and beyond. Numerous studies have focused on the protagonists and the extraordinary projects they designed, often challenging the limits of calculation and construction site technologies of that time. At present, however, the period of their gradual decline remains uncertain and unexplored and is generically attested to be between the 1970s and 1980s.

In 1971, Anton Tedesko, a well-known engineer involved in shell design and construction in the USA for more than 40 years, provided a broad insight on the history of the application of shells in the USA based on his professional experience, focusing on the latest trends (Tedesko 1971). He described a detailed framework of the reasons behind the changes in the diffusion and application of shell structures until the end of the 60s. But what happened during the following decade?

This paper aims to contribute to the description and discussion of the so-called last season – and currently less studied – of the thin concrete shell structures in the United States of America, starting from the event connected to the sudden collapse of the Tucker High School gym that occurred in September 1970, a paradigmatic, although apparently minor episode, in the wider history of construction. Built in 1962, the failure of the gabled type hypar structure resulted in a fervent debate regarding both the accuracy of the calculation methods used and safety of this type of concrete shell. It went beyond the simplification of the membrane theory and the diffusion of a few design guides. Although the architectural structure that was impacted by this collapse was not a renowned one, this peculiar event can be added to the extensive list of already known failures in the history of construction innovations that require further research and knowledge development.

This research was conducted using the archival documentation preserved as part of the Anton Tedesko Papers (Princeton University Library) – including correspondence, research and original project drawings – and a review of the scientific literature published at the time (ACI and ASCE database). Although the 70s can undoubtedly be considered far from the design and construction fervor of the 50s, that period was characterized by seminal scientific contributions that have been anything but secondary. Retracing the history of the gym project, the collapse and consequent scientific impulse, the research points out how during the 70s the boundaries of the knowledge of shells' mechanical behavior were pushed as never before, supported by the use of early software based on finite element numerical calculation.

2 THE TUCKER HIGH SCHOOL GYM: PROJECT AND COLLAPSE

On 14 September 1970, the gymnasium of the Tucker High School in Henrico county, Virginia, suddenly

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collapsed (Figure 1). The building was constructed in 1962 by R.L. Bulifant & Co. (Richmond) and designed by Thomas A. Hanson & Associates engineering firm, under a subcontract from J. Henley Walker Jr. who designed the school complex (Students clear 1970).

At that time, the news aroused some interest, among both public opinion and insiders in the structural engineering field. A few school gyms, even in the same county, were designed with the same hypar shell system. Generally, the configuration used in the collapsed building was among the most widespread and applied in the United States of America for this kind of structure, due to its functional and constructive advantages.

Among the statements that the designer released after the event, one, in particular, drew the attention of specialists in shell design. Hanson claimed that “reference for the design was a report of an elementary analysis of hyperbolic paraboloid shells published by the Portland Cement Association of Chicago” (Design errors 1970). Although the title was not mentioned, it is reasonable to assume that it is referring to *Elementary analysis of hyperbolic paraboloid shells*. A first version of this design guide was published by the Portland Cement Association of Chicago in 1958 (Elementary Analysis 1958) and a second in 1960 (Elementary Analysis 1960), briefly collecting the state of knowledge on the design and analysis of this type of structure (Figure 2). The report does not mention the author, but it is likely that Alfred L. Parme was involved, as engineer in the Structural and Railways Bureau of the Portland Cement Association and author of two articles on double-curved shells, including hypars (Parme 1956, 1958). Moreover, the content of the report takes the approach presented by Parme in his articles, assuming the hypar as a geometry consisting of two orders of parabolic arcs and providing parametric tables to facilitate the calculation. If the design of the Tucker gym had followed the recommendations of the Portland Cement Association – as stated by the designer – understanding the causes of the collapse would be essential to evaluate whether the design methodology used for hypar roofs was really safe.

The hyperbolic paraboloid roof of the gymnasium belonged to the so-called gabled or hipped type (Figure 3). The area of 32 × 32 m was covered by four sections of hypar, resting on four columns at the corners with 55 × 55 cm section and 3.5 m height (Figure 4). As this aggregative typology suggests, the framing of this structure was composed by four edge beams, four tie beams, and two ridge beams.

The edge beams were placed at the intrados of the shell, with a constant width of 37 cm and a variable depth between 45 and 60 cm; the tie beams had a constant section of 37 × 43 cm, with a post-tensioning system that included Freyssinet anchorages; finally, the ridge beams were designed as an enlargement of the shell depth of 21 cm, with a variable width from 76 cm near the edge to 238 cm near the center of the shell (ATP; Figure 5).

Each shell had a thickness of 8 cm and was constructed using a lightweight concrete and double layer of steel mesh, with orthogonal direction to each other. The total free span of the hypar roof was 32 m while the maximum rise was 4.5 m. The project also included a decentering plan, describing the sequence of the screw jacks turning to remove the formwork.

After the collapse, a technical commission was immediately established to determine the reasons for such an unexpected event. The commission included Richard Elstner of Wiss, Elstner & Associates (Northbrook, Illinois), William A. Stuart of Wiley & Wilson (Lynchburg, Virginia), and David Morris of the University of Virginia (Charlottesville, Virginia). Also

Figure 1. Gymnasium of the Henrico High School, Virginia, a gabled-type hypar shell structure similar to the Tucker High School (*Students clear*…1970).

Figure 2. The collapsed shell structure of the Tucker High School (*Richmond Times* Dispatch).

CONCRETE INFORMATION

Elementary Analysis of
Hyperbolic Paraboloid Shells

Figure 3. The design guides of the Portland Cement Association: on the left the covers of the first edition (1958), on the right the second edition (1960).

included in the investigation by Richard Elstner was Milo Ketchum – a well-known engineer, academic, and designer qualified in shell structures.

An in-depth analysis on the structural materials excluded causes linked to maintenance, deterioration of the structures, poor quality of the building materials, and improper construction processes. The commission concluded that "the failure [...] was due to the design, which did not take into effect, fully, the magnitude of secondary moments or stress, which were established and building up over a period of time" (Design errors 1970). The report also described the analysis carried out on the other three school gyms built with the same system, showing a considerable deformation in the ridge beams, induced by a significant lowering of the center of the shell.

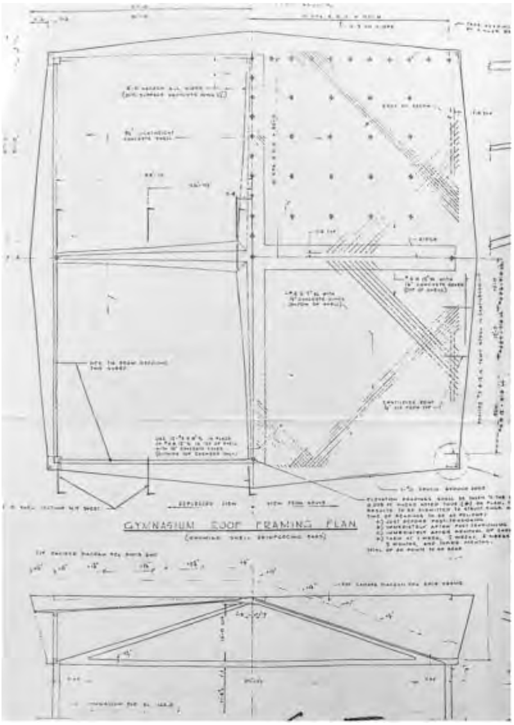

Figure 4. Original project of the Tuckers' gym (ATP).

Milo Ketchum claimed he had measured a drop of 45 cm in one of these, a factor that contributed to the decision to preventively demolish the other similar gyms for safety reasons (MKS).

3 RESEARCH IMPULSES

What kind of consequences could the Virginia failure on the design of hypar thin shell roofs in the USA have had? In the previous decades, shells based on quadric surfaces had been favored for their high performance, simple calculation (thanks to the known equation), economy on the construction site and architectural allure (Joedicke 1963). However, during the 70s, hypar shells gradually lost their appeal, as if their expressive potential had been consumed. New shapes for shells were not only a theoretical interest, but also an opportunity to search for new construction techniques (Isler 1961) and to apply the first attempt of digital drawing (Barnet 1965).

Nevertheless, the academic and scientific interest in concrete thin shells with quadric surface – especially the hypar – did not decrease quickly. This was due to the most advanced computational opportunities offered by numerical methods implemented in the earliest research software giving researchers new ways to describe in depth the mechanical behavior of these kinds of structures. The collapse of the gym had

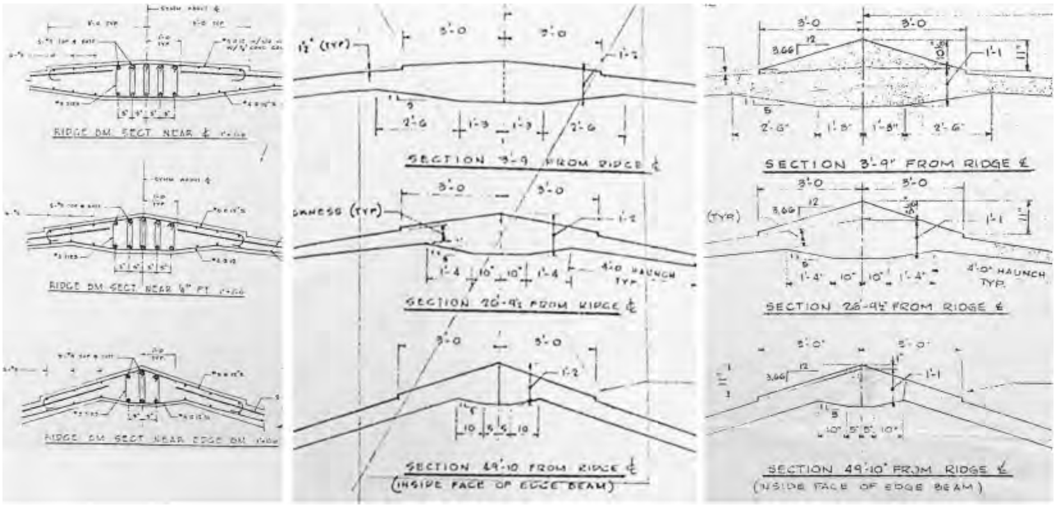

Figure 5. Original project details of the ridge beams of the Tucker gym (ATP): on the left the stiffening, in the middle the geometry originally design, on the right the realized ridge beams (ATP).

revealed a knowledge gap to be filled, for both the safety of new projects and existing buildings.

At the forefront of the constant advancement in mechanical and constructive knowledge of shells in the USA were the members of the American Concrete Institute (ACI) Committee 334, entitled “Concrete Shell Design and Construction.” Examining the sessions organized at the ACI Conferences and Annual Symposiums, the works of the ACI Committee 334 and the papers published in the ASCE/ACI journals by its members, it can be observed that during the 70s there was fertile scientific production, although less exposed to the media of previous decades. The results of these studies, some linked with the failure in Virginia, help to identify the reasons for the collapse and to increase an awareness in the design and monitoring of these kinds of structures.

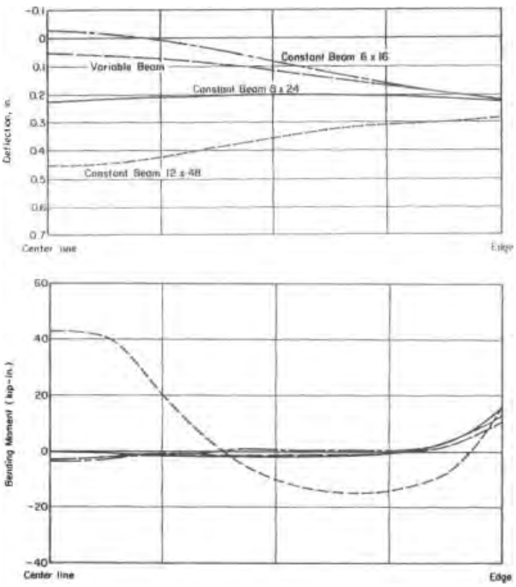

Figure 6. Schnobrich results: above the normal deflection in ridge beams with different sizes, below the bending moment in ridge beams with different sizes (Schnobrich 1972).

3.1 *Towards understanding the bending behavior: Schnobrich (1972) and Shaaban-Ketchum (1974)*

During the 70s, many studies were published in the field of mechanical analysis of hypar shells. Considering the gable-type configuration, two papers stand out: that of William C. Schnobrich in 1972, of the University of Illinois, and that in 1976 of Ahmed Shaaban with Milo S. Ketchum, of the University of Connecticut. These studies examined the bending behavior of the gable-type hypar, applying for the first time the finite element method (fem) (Turner et al. 1956) to this aggregative configuration, which was already considered the most promising method for this shape (Schnobrich 1971). The use of this type of numerical calculation in the early research software allowed engineers to understand the role of the ridge beams in this type of roof (Schnobrich 1972) and to point out the actual stresses in the shell considering the effect of edge beams, comparing them to the results obtained using membrane theory (Ketchum 1976).

Both studies consider the same case study for configuration type and geometry: a gable-type hypar shell with a total span of 24.4 m (80 ft) and a rise of 2.4 m (8 ft) (Figure 2), similar to the collapsed gym in Virginia. Moreover, both applied the same method of analysis, using the fem in early software arranged for research purposes. As a result, these two studies paved the way for an in-depth analysis of this type of structure.

With his paper “Analysis of hipped roof hyperbolic paraboloid structures”, Schnobrich (1972) aimed to investigate the relationship between the shells and the supporting or stiffening members, exploring the stresses developed in the edge and ridge beams in a gable-type hypar structure. The approximations of the membrane theory do not allow identification of the possible effect of the supporting members’ weight on the shell, since the supporting beams had to be analyzed separately from the shell, resulting in erroneous estimations. This paper reports the variation in the mechanical behavior of the structure when geometry and weight of the ridge beam change, demonstrating how the dimensions of the beams affects the overall performance of the structure. In particular, faulty design of the ridge beams can have a detrimental effect on the expected performance of the shell.

For his study, Schnobrich used software developed by T.C. Chu in collaboration with the Office of Naval Research, pointing out a few unknown aspects of the hypar mechanical behavior. Among these aspects, he observed that, at the center, the shell carries the dead weight of the ridge beams and not the reverse, concluding that the stresses in the supporting members are not effectively predicted by the membrane theory. Using a large member as ridge beams should therefore be avoided, since the unnecessary weight would cause more than one detrimental process to the general behavior of these types of structures (Figure 6).

In the paper entitled “Design of hipped hypar shells”, Shaaban and Ketchum (1976) analyzed the stresses in the shell using fem calculation with the aim of giving more accurate suggestions for the preliminary design. The authors refer explicitly to the Virginia failures and to Schnobrich’s research, considering the same case study. Going beyond the membrane theory, the results show, with unprecedented accuracy, the bending behavior of the shell and the mechanical relationship between shell and edge beams.

The authors clearly report the in-plane shear forces, the in-plane membrane forces, the principal compressive stresses in diagonal arch, and the bending moment of the shell. Critically analyzing the results, Shaaban and Ketchum firstly showed that the membrane acts as two crossed parabolic arches spanning across diagonally opposite supports. As pointed out in the diagram of the direction of principal stresses in membranes, the arched action in the shell is considerably higher than the catenary one. Secondly, the authors gave indications for the design of the edge beams, including some consideration about the eccentricity between beams and shell (Shaaban, unpubl.). Finally, Schnobrich's results on the ridge beams were confirmed, suggesting that these members should be designed as a gradual thickening of the membrane itself.

The results of these two papers show how the finite element method allows for investigating the bending behavior of the gable-type hypar, going beyond the membrane theory, which reveals its limits. Both papers, in conclusion, provide detailed indications for the correct sizing of the stiffening members of this kind of structure. Considering the collapsed gym in Virginia, the most significant result was that an increase in the ridge beam weight causes a consequent increase in the bending moment in the center of the shell. This induces deformation in the beams and a consequent change in the shape of the shell, which loses its peculiar form resistance (the parabolic arch). Besides the important progress in the identification of the causes of the Virginia failure, these studies suggested for the first time that all the elements involved in these types of shell structures act as a single system. There is no precise hierarchy of elements in the structure, therefore they are not classifiable among load bearing and load.

3.2 *The influence of the parabolic arch deformation: Stuart's research (1973–4)*

In October 1974 the ACI Fall Convention, in Atlanta, Georgia, hosted a panel entitled "Lessons learned from failures of concrete structures: The Gymnasium roof of Tucker High School, Richmond, Virginia" (ACI 1974). Moderated by 334C Secretary John E. Breen (University of Austin, Texas), the session included speeches by Thomas A. Hanson, owner of the engineering firm that designed the gym, Richard C. Elstner and William A. Stuart, engineers of Wiley & Wilson inc. (Virginia) and members of the technical commission established after the event, and Mark Finter, director of engineering design and standards at the Portland Cement Association.

The organization of this panel originated from a connection between Stuart and David P. Billington, professor at Princeton University and previously engineer at Roberts & Schaefer Company. It started in April 1973, as documented by correspondence in the Anton Tedesko Papers of the Princeton University Library (ATP).

Through the correspondence, which also involves Alexander C. Scordelis of the University of California Berkeley (editor with S.J. Medwadowski and W.C. Schnobrich of the proceedings of the Concrete Thin Shell Symposium of the ACI Committee 334 held in New York in April 1970), it is possible to see how the collapse encouraged the research interests both of academics, for scientific interest, as well as designers and engineers of similar structures.

Discovering the interesting results of the technical commission, Billington encouraged Stuart to submit a paper to the ACI Annual Symposium or the ASCE journal, with the aim of illustrating the design method of the gym, its collapse and the investigation of the technical commission, including the analytical method used to evaluate the collapse mode. Beside the abstract shared by Stuart with Billington as preview, in the ACI and ASCE repositories there is no paper written by Stuart. Legal problems connected with the collapse likely prevented its publication. Nevertheless, the initiative demonstrated by Stuart led, the following year, to the organization of the panel for the ACI Convention in which he presented a significant contribution, the notes of which are preserved in the ATP.

In line with the results reported by Schnobrich (1972), the research conducted by Stuart in 1973–4 confirms the sensitivity of the gable-type hypar to shape change. Stuart developed a mathematical model of the gym to determine how sensitive this type of structure is to geometry alteration. He considered firstly an initial change in the geometry induced by creep and shrinkage (second-order effects), then the subsequent elastic deformations of the structure. Through an iterative numerical analysis, the investigation explains how gradually the gable-type hypar tends to a lowering of the center of the shell. This progressive deflection induces a significant change in the curvature of the compressed parabolic arch, which loses its characteristic form resistance that will cause the collapse.

In view of the results of Stuart and Schnobrich, the ridge beams appear to be crucial for the safe design of a gable-type hypar. The sizing of these stiffening members shall be optimized to reduce the dead load, avoiding weighing down the central area of the structure, since it is an area of minimum resistance, where the parabolic compression arches become horizontal.

The studies carried out in those years help explain the reasons for the sudden collapse of the gym in Virginia. Thanks to a letter dated 1977 (ATP) from Stuart to Billington, it is possible to learn that during construction the thickness of the ridge beam had been increased from 37 cm to 56 cm (Figure 1). The excessive weight of this element had induced an unusual lowering of the center of the shell, which in turn had provoked the change of the curvature in the parabolic arch. Since the peculiar characteristic of this type of structure to resist by form, the collapse was caused by the deformation of the most significant element. The shape that the shell had taken was no longer able to resist according to the nature of the structures.

3.3 *The ACI committee 334: From "Concrete thin shell" (1970–1) to "Concrete shell buckling" (1979–81)*

The collapse of the gym helped to identify the stability of shells as a pivotal subject for future research, which in the early 70s it was possible to approach using numerical calculation and computer systems.

Figure 7. Committee 334 Symposium proceeding: on the left the event of 1970, on the right the event of 1979.

Figure 8. The covers of *Thin Shell Concrete Structures* by David P. Billington: on the left the edition of 1965, on the right the edition of 1982.

It is interesting to compare the contents of the proceedings of the Symposium organized by ACI Committee 334 held in 1970 and in 1979 (Figure 7). The papers collected in the proceedings of 1971 (Medwadowsky et al. 1971) show broad contents in different fields of research, from theoretical aspects (Tedesko, Medwadosky, Parme) to project experiences (Christiansen, Ketchum, Candela), from construction techniques (cast-in-place vs precast) to the mechanical analysis of different shell types. The proceedings of 1981 (Popov & Medwadowsky 1981), instead, focus on a single theme – the stability of shells – and the papers contained therein are written by researchers mainly in the field of structural mechanics (i.e. Scordelis, Abel, Gould, & Schnobrich).

In these differences, it is possible to read not only the urgency felt for the theme, but also of the gradual evolution of engineering towards highly specialized research and the consequent decline of a holistic approach for design, which considers architectural, construction, and structural aspects as a single design process. In this context, the conference of 1970 can be considered an end of the previous age and the decade of the 70s as a transition period: from the age of master builders to the age of computers, from a material approach (analog) to a non-material one (digital).

Among the cornerstones in the ACI Committee 334, it is possible to include David P. Billington who included many of the results of previous contributions in the second edition of *Thin shell concrete structures* (the first edition was in 1965) (Figure 8), expanding the chapter regarding the hypar shells (Billington 1982, 258–90) and adding a whole chapter about the "stability and safety of shell" (Billington 1982, 311–29). In the latter, Billington cites the collapse of the gym in Virginia, explaining the role of the ridge beam weight in the middle of the roof and the role of creep, made worse in this case by the use of lightweight concrete which was more prone to creep (Billington 1982, 325–8). However, he did not mention the increase in the ridge beam thickness, information that was probably not disclosed for legal reasons at the time of publication.

Billington also notes that the state-of-the-art technology in 1962, when the Virginia shell was designed, did not allow for correctly calculating the shell and beam stresses, due to the use of membrane theory. Nevertheless, he emphasizes that Anton Tedesko had already observed in 1958 how the lack of curvature in the center of the shell made it a critical area from the standpoint of buckling. For this reason, in designing the hypar in Denver (for the Roberts & Schaefer Company, with I.M. Pei), he added more stiffening in the central area (Tedesko 1960). After the collapse of the Tucker School gymnasium, the local administrations decided to demolish the other three gyms designed using the same system by the same engineering firm. It is not possible to verify if Billington had wanted to defend the hypar in Denver from possible criticism caused by the growing skepticism for this type of structure. However, he undoubtedly felt the need to make the necessary distinctions between apparently similar cases, but actually extremely different.

4 CONCLUSIONS

Although the collapse of the gym in Virginia at the beginning of the 70s may appear to be a minor event in the wider construction history of the USA, it paved the way for further studies on shell structures, influencing research topics for the following years. This is confirmed by Billington's statements (1982, 325) in the second edition of his book and the seminal works developed during the 70s, most of all the proceedings of the ACI Symposium "Concrete Shell Buckling".

With the development of the computer, at the beginning of the 70s, the time was ripe for the application of the finite element numerical calculation to the analysis of the hypar shells using early research software. This factor was decisive for obtaining concrete results in investigating both the mechanical interaction beam-shell and the global stability of these structures. Moreover, the membrane theory finally revealed its inadequacy, particularly evident if the designer needs to calculate shells with a very large span (e.g. Denver's hypar) or very low rise, or if they apply that theory without a broad experience in designing these types of structures – a crucial aspect of what happened with the gym in Virginia.

Researchers and designers across the USA gathered in ACI Committee 334 – including Alexander C. Scordelis, David P. Billington, William C. Schnobrich, Milo S. Ketchum, William A. Stuart – led the research and produced the main results on the gable-type hypar shell, confirming today the essential role of the ACI Committee 334 in the history of shells in the USA, as both supervisor and active researcher.

Despite the 70s generally being considered a period of sunset in the history of extensive design and construction of shell in the USA (Tedesko 1971), it would be better to consider the years as a period of transition, associated with fervent scientific research. During the 70s, unprecedented results were reached that transformed the design approach of hypar shells and, more generally, of the shell structures themselves.

Through the present research some pivotal papers were identified, relevant even today for careful analysis of the architectural heritage designed during that period with shell structural systems, in order to correctly approach their preservation and restoration within a historical perspective.

Defining the 70s as the end of the shell era neglects some important aspects of that period. The present brief, but not exhaustive, research on the scientific impulse during the 70s in the USA has shown possibilities for further developments of research. A more in-depth insight should be undertaken into the projects realized in that decade, to: evaluate their magnitude, geographical collocation, functions, and characteristics; identify the main designers of that period, including Milo S. Ketchum (Boothby et al. 2012) and John V. Christiansen (Sprague 2019); detect the engineering firms and construction companies involved. To achieve a broader picture of the shell era in the USA, the systematic investigations already in progress, on significant figures such as Anton Tedesko (Hines & Billington 2004, Silman 2011) and David P. Billington (AA.VV. 2020), whose professional and research activity were very prolific, should be continued.

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Thematic session: Can Engineering culture be improved by Construction History?

History of Construction Cultures – Mascarenhas-Mateus & Paula Pires (eds)

The potential roles of construction history in engineering education

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ABSTRACT: This paper identifies the potential roles for construction history in engineering education and engineering culture. The paper acknowledges that engineering culture varies with region and with time. The paper equates engineering culture, in the context of construction, with the pragmatic application of reason, mathematics, applied science, economics and experience to building and infrastructure projects. Engineering culture is influenced by the academic training of engineers and technicians, and the work practices that have evolved within the engineering profession. The paper makes the case that including construction history in the engineering curriculum would improve the learning outcomes achieved by engineering programmes and hence would have a positive effect on engineering culture.

1 INTRODUCTION

The overall purpose of any professional education is to prepare students for entry into their profession. At a minimum, this involves imparting any necessary skillset and essential information. However, the study and application of the professional skills also moulds the way in which students approach challenges, the way they think and what they accept as the norms of their profession. In the case of an engineering degree, the result is to form engineers who are problem solvers with a skillset that includes mathematics and the relevant sciences, and designers with a knowledge of design and construction practice. Engineers must also develop a knowledge of how their profession interfaces with other professions and with society.

Civil engineers and structural engineers study structural design, material science and a range of other specialist subjects that are relevant to the design, construction, operation and maintenance of infrastructure. University prepares engineering students for entry to the profession but professional bodies require graduates to practice engineering and work in a variety of roles before they can become chartered Engineers. This recognizes that experience gained through professional practice is necessary to complete the training of a professional engineer. In the case of engineering technicians, the skillset is different but the overall approach to training and professional recognition is similar.

Although some aspects of engineering education have changed, many have remained constant since the founding of the École des Ponts et Chaussées in 1747. This commonality of engineering education plus practice leads to a situation where engineers from different backgrounds working in a team have similar viewpoints on what their role comprises and how their goals should be achieved. This shared experience of education and practice could be described as engineering culture. This paper argues that including the study of construction history in engineering programmes will have a positive impact on engineering culture.

2 ENGINEERING CULTURE

The term engineering culture is vague; its meaning has varied over time and with location, and it is not always homogeneous. For example, professional engineers in the United Kingdom during the first half of the 19th century came from a wide variety of backgrounds. Some, like Thomas Telford or George Stephenson, had started as tradesmen whereas others, such as Isambard Kingdom Brunel or John (later Sir John) Rennie, had also had the benefit of a university education (Skempton 2002, Cross-Rudkin & Chrimes 2008). These different backgrounds are reflected in some of the discussions that followed papers that were given to the Institution of Civil Engineers (ICE) at that time, where the contributions offered often reflect the perspective of the contributors (O'Dwyer 2020). There was also a difference, or a perceived difference, between the engineering discipline in France and in the UK arising from the different modes of educating and training engineers. Thus, in the past, French engineers might be assumed to lean towards a more scientific view of engineering while engineers from the UK might have viewed themselves as more pragmatic, with an emphasis on practice. These divisions, whether real or imaginary, play into different interpretations of what engineering culture encompasses. However, at the heart of engineering culture there is a kernel of attributes that are widely recognized as being common within the engineering profession, namely: the application of rational techniques and pragmatic numerical models to solve problems. Engineers involved in construction also rely on a knowledge of the properties of the materials used in building and an appreciation

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Figure 1. Robert Stephenson – Britannia Bridge (courtesy of the ICE).

of the logistics and economics associated with building work. If an image were to be chosen to represent engineering culture in the 19th century then the painting that hangs in the Institution of Civil Engineers headquarters of Robert Stephenson with his rivals and colleagues in front of the Britannia Bridge would be a strong contender (Figure 1).

For the purposes of this paper, engineering culture will be taken as a pragmatic approach to problem solving that is based around mathematics and the relevant sciences combined with professional practice with regard to design and construction.

The rest of the paper presents a series of arguments for the inclusion of construction history within civil and structural engineering programmes.

3 ENGINEERING ACCREDITATION

Modern engineering programmes are heavily influenced by accreditation criteria. The routes to becoming a chartered engineer differ from country to country, with regulatory control usually resting with a state-recognized organization that is responsible for maintaining a register of qualified engineers. Sometimes the regulatory body is also the professional engineering association. Although this system seems chaotic, in practice most engineering regulatory bodies, such as the European Network for Engineering Accreditation (ENAEE), which awards the EUR-ACE® (EURopean-ACcredited Engineer) label, are part of larger international mutual recognition agreements like the Washington Accord. This has the effect of ensuring uniformity in the learning outcomes delivered in most engineering undergraduate programmes across the world. Thus, the Accreditation Board for Engineering and Technology, Inc. (ABET), and ENAAEE have similar accreditation criteria (ENAEE 2015, ABET 2019).

Modern accreditation criteria for engineering undergraduate programmes are not prescriptive in the detailed content that must be included in the programme. Instead, the desirable learning outcomes are specified under programme area descriptors. The details of these areas and the required outcomes differ slightly from accreditation body to accreditation body but the ENAAEE Framework Standards and Guidelines (ENAEE 2015), which all European engineering registration bodies seek to satisfy, lists the programme learning areas as:

- Engineering Analysis;
- Engineering Design;
- Investigations;
- Engineering Practice;
- Making Judgements;
- Communication and Team-working;
- Lifelong Learning.

The modules taken by a student on an accredited programme are required to enable master's degree graduates to demonstrate their competence in each of these learning areas. Although a detailed knowledge of the graduate's field of engineering is required, the accreditation criteria do not specify the specialist areas that must be covered. There are so many technical areas within modern civil or structural engineering that it is challenging to find space in the modern curriculum for niche areas. Rich specialisms, such as construction history, are easier to accommodate in specialist master's programmes.

The pressure on space within undergraduate engineering curricula means that dedicating a full module to construction history is a challenge. This is not to imply that construction history is ignored in engineering programmes: most lecturers are interested in outlining the history of their field. Thus, one can expect engineering students to gain some knowledge of the history of construction materials, of the history of structural analysis and of the history of the engineering profession. Unfortunately, this is likely to be scattered across the curriculum.

Although including the study of construction history within an engineering degree, first or second cycle, is difficult to justify on the basis of the related topic-specific knowledge, there are other very strong grounds for including construction history as a core component of such degrees. The rationale for including construction history is based on the ENAEE requirement that graduates should be able to demonstrate the abilities listed below under the headings, Making Judgements, Engineering Practice and Engineering Design (ENAEE 2015).

3.1 *Engineering design*

- ability to develop, to design new and complex products (devices, artefacts, etc.), processes and systems, with specifications incompletely defined and/or competing, that require integration of knowledge from different fields and non-technical – societal, health and safety, environmental, economic and industrial commercial – constraints; to select and apply the most appropriate and relevant design methodologies or to use creativity to develop new and original design methodologies.

- ability to design using knowledge and understanding at the forefront of their engineering specialization.

3.2 *Engineering practice*

- comprehensive understanding of applicable techniques and methods of analysis, design and investigation and of their limitations;
- practical skills, including the use of computer tools, for solving complex problems, realizing complex engineering design, designing and conducting complex investigations;
- comprehensive understanding of applicable materials, equipment and tools, engineering technologies and processes, and of their limitations;
- ability to apply norms of engineering practice;
- knowledge and understanding of the non-technical – societal, health and safety, environmental, economic and industrial – implications of engineering practice;
- critical awareness of economic, organizational and managerial issues (such as project management, risk and change management)

3.3 *Making judgements*

- ability to integrate knowledge and handle complexity, to formulate judgements with incomplete or limited information, that include reflecting on social and ethical responsibilities linked to the application of their knowledge and judgement;
- ability to manage complex technical or professional activities or projects that can require new strategic approaches, taking responsibility for decision making.

The study of construction history is an ideal route to developing competence in these programme areas. Construction history can be used to study: the history of engineering failures and success, the history of the development of construction materials and material testing, the development of methods of structural analysis, the development of different construction forms and methods of construction, and the nature of the engineering profession including the relationship between clients, consultants and contractors and the emergence of university engineering education. The study of construction history can be used as a vehicle to allow students to study a wide variety of case studies that explore: the development of new building technologies, the development of innovative solutions and their associated risks, economic constraints, the balance between theory and pragmatism, the importance of careful project management, and the challenges associated with building with new materials.

Although the history of construction inevitably deals with the past, it can focus on developments that were new or novel when first introduced. Furthermore, many of the novel developments occurred before the advent of reliable material tests or advanced methods of analysis. Thus, the history of construction is an ideal topic for exploring how engineers and other professional can make decisions with limited information. The different benefits that arise from the study of construction history are considered in the sections which follow.

4 KNOWLEDGE OF MATERIALS AND CONSTRUCTION TECHNIQUES FROM THE PAST

The increased knowledge of construction materials and construction techniques from the past is clearly very useful for any practicing engineer. Many building projects involve the retention, restoration or repair of older structures and this work requires expertise in the history of construction. Conservation work is often overseen by conservation architects, but more recently engineers working in the field of conservation engineering have become organized and there is now a register of conservation engineers, CARE (Conservation Accreditation Register of Engineers), that is maintained by the Institution of Civil Engineers, The Institute of Structural Engineers and Engineers Ireland. This register is based on similar registers of conservation architects. Thus, including construction history in the engineering curriculum has direct benefits for structural engineers, particularly those dealing with conservation projects. However, there are a myriad of potential subject areas that would be of specific benefit to engineers working in particular specialist fields that cannot be covered adequately in the first or second cycles of an engineering education. Thus, the thorough study of past construction materials and techniques must be delivered in specialist educational programmes and supported by appropriate case histories and papers published in the relevant engineering journals.

5 KNOWLEDGE OF PAST FAILURES AND SUCCESSES

It is important to learn from one’s mistakes and from the past mistakes of others. Every past failure presents lessons for the profession. Studying a single failure will acquaint students with the cause or causes behind the failure but when multiply failure case-studies are studied, students will learn general lessons. They will identify failures that occurred due to poor communication, or poor supervision. They will notice that an inadequate understanding of material properties has caused numerous failures. They will appreciate that some analysis techniques are valid only when certain assumptions are met and will appreciate the need for rigorous testing of materials.

There have been many publications analysing engineering failure (Cowan 1992, Levy & Salvadori 1994, Petroski 1994, 2005, Scheer 2010, Sibly & Walker 1977 and Smith 1976). There have also been publications on the educational benefits of studying past failures by Jennings (1995) and O’Dwyer

(2013). Similarly, the educational benefits of studying previous design successes have been described (O'Dwyer 2013). There are many benefits to studying the building profession's past failures and success but core among them is the fact that studying the lessons from past construction successes and failures is probably the best way of developing engineering judgement. This is one of the strongest reasons for including construction history in the curriculum. The study of failures also demonstrates how the profession responds to failure by changing professional practice or other aspects of engineering culture.

6 ENGINEERING DESIGN

The lessons learned from studying construction history also inform engineering design. The two bullet points relating to engineering design in the ENAEE guidelines require students to be able to use state-of-the-art knowledge in design and to recognize that a successful design must meet a range of criteria ranging from sustainability to societal impact and from health and safety to economic considerations. Furthermore, the guidelines specify that graduates should be able to design in the absence of complete knowledge. Thankfully there is a rich history of significant design examples that demonstrate the multitude of criteria that a successful design must address (Addis 1989, Mainstone 1983). For example, projects ranging from the design of the gothic cathedrals (Cowan 1992, Heyman 1995), to the construction of the Dome of the Santa Maria del Fiore by Brunelleschi (King 2008), to the 20th-century shells of designers like Nervi and Torroja (Nervi 1966, Torroja 1958) show innovators operating at the cutting edge of contemporary building technology.

The discipline of construction history is multifaceted. Those studying in the field examine the technical aspects of construction, the maintenance and operation and use of the structures, the economics of construction and the societal impact of construction. Thus, the study of construction history addresses accreditation requirements that are difficult to address with a traditional engineering design module. In addition, the case studies encountered in the study of construction history often involve the first use of novel methods. Thus, although construction history deals with construction methods that may be obsolete now, these techniques were at the cutting edge when they were used. The examples of the Menai Strait bridges of Telford (Provis 1828) and Stephenson (Clark 1850) are perfect examples. Robert Stephenson's Britannia bridge was a significant technical leap. Stephenson's bridge was the result of extensive mathematical and experimental work at the cutting edge of technology (Figure 2).

Figure 2. Construction of the Britannia Bridge (Clark 1850).

The study of engineering design in the context of construction history has another particular benefit for the modern engineering student. In the last few decades, the availability of structural analysis software has increased to the extent that one can assume that software will be used to analyse all significant engineering structures. Engineers from previous generations could only dream of having the ability to analyse complex structures in detail. It is, therefore, instructive to realize that engineers were willing to construct complex shell structures in the middle of the 20th century, when they had great difficulty analysing them accurately. Engineers like Nervi and Torroja worked carefully from first principles and used models and test structures because the realized that they were working without the benefit of full knowledge (Nervi 1966, Torroja 1958). Examples such as these are useful for demonstrating to students that working without full information is not only possible but is frequently the norm.

7 ENGINEERING PRACTICE

The technical aspects of engineering practice, such as how to analyse an engineering problem or develop an appropriated model of a system, are core to engineering education. However, the accreditation criteria require evidence that students appreciate the role of such skills within engineering practice and require students to understand how the engineering profession provides solutions that are economic, sustainable and meet society's needs. The study of construction history is a good vehicle to achieve these learning outcomes.

George Semple's description of his reconstruction of Essex Bridge in Dublin, “On Building in Water” (1776), is one of the earliest civil engineering texts written in English (O'Dwyer & Cox 2012). It is a very good example of how the study of an historic construction project can be used to explain engineering practice. The reconstruction of Essex bridge is particularly suitable because of Semple's candour (Figure 3).

He outlines how he secured the contract, his problems getting technical information, his consultation with experts outside his field and the near disasters he encountered during construction. His illustrations and technical commentary are also excellent, particularly

Figure 3. Essex Bridge 1753–55 (Harris 1766).

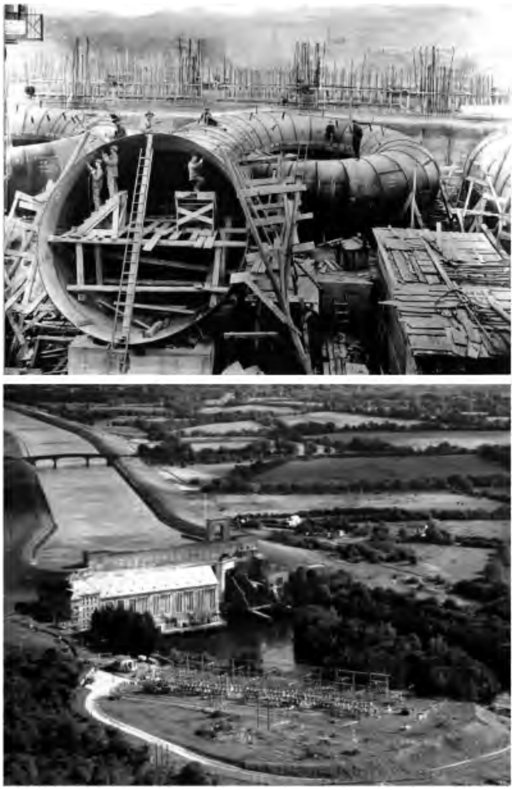

Figure 4. Penstock Ardnacrusha hydroelectric station (courtesy ESB Archives).

because they show his desire to bring reason to bear on technical decisions. This enlightenment attitude is still at the core of engineering culture.

The construction of the 90 MW Irish hydroelectric dam at Ardnacrusha on the river Shannon is an example of a significant engineering project that demonstrates the interaction between the engineering profession and society (ICE 2018) (Figure 4).

This dam was constructed between 1925 and 1929 by the fledgling Irish State. At the time of its construction it was one of the largest civil engineering projects in the world. The project was at one and the same time both a political statement and an essential infrastructure project. The inspiration for the scheme came from a young Irish engineer, Dr. Thomas McLaughlin, who was employed by the German firm Siemens-Schuckert. The dam required a workforce of 5000 workers including 150 German workers and engineers. The hydroelectric dam produced more that 100% of the energy needs of the country on its construction.

Its viability was dependent not only on it being completed successfully but on increasing the demand for energy so that the power produced could be sold in quantity at a price that could pay for the hydroelectric dam's construction. Ensuring the success of this engineering project required a reorganization of Irish rural society. This project is a good example of the role of the engineering profession in transforming the way in which people live. Other significant construction projects, ranging from the drainage of the Fucine lake to the excavation of the Suez and Panama canals or Bazalgette's London sewerage system, make excellent case studies. It is also possible to follow a theme, such as coastal defence, and observe how engineering practice has evolved from earliest times to the present. Projects such as the reconstruction of flood defences for New Orleans (ICE 2018) demonstrate how the engineering and other building professions interact with each other to provide the infrastructure that society depends on.

8 ASSESSMENT

Strong arguments have been presented that the study of the history of construction is a very good method of covering topics such as professional practice, studying how engineers in the past have progressed with incomplete information, and examining how the profession learns from successes and failures: topics that are difficult to cover in an interesting way when studied on their own. However, one aspect of the accreditation system poses a challenge. When programmes are assessed, the general rule is that it is not sufficient to simply cover material in the programme: it is important to demonstrate that the students' competence in an area has been confirmed via assessment. This presents a challenge because it is best to demonstrate the required competences by setting the students questions related to current practice. Thus, for example, to allow a student to demonstrate the ENACC requirement listed below,

- ability to manage complex technical or professional activities or projects that can require new strategic approaches, taking responsibility for decision making.

it is easiest to give the student a scenario in the present. Unfortunately, this could result in the student perceiving a mismatch between the construction history material and the examination. One way of overcoming this difficulty is to ask the students to provide examples from the history of construction that support the decisions or approach that they are advocating. The text below is from a 4th-year engineering examination that was taken by students in Trinity College Dublin.

> *Johnson & Gill Chemical Ltd. have commissioned a short (50 m span) suspension bridge to provide pedestrian access to their research campus. The firm has developed a novel material comprised of layers of nanocellulose film and want to use the bridge to showcase the material. In the laboratory the material has shown strengths of over 200 MPa, high stiffness (around 20 GPa) and high strain (12%). It is imperative for the reputation of both Johnson & Gill, and your consulting firm, that the structure is a success. Tomorrow morning you will address your design team and want to impress on them the need to minimise the potential risks that are inevitably associated with novel designs and novel materials. Identify the key points that your presentation should address in order to highlight the lessons that can be learned from previous structural disasters and the key strategies that should be adopted to minimise risk.*

The students who answered this question had studied a range of historic structural engineering failures and successes. They had reviewed the case histories of the Tacoma Narrows bridge, the failure of the Dee bridge the dynamic problems encountered by Telford's Menai Straits bridge (Day 2012) and the Millennium bridge, the failure of the Liberty ships and Comet aircraft, the problems caused by detailing in the Hyatt walkway, the failure of the façade elements on the John Handcock building and the successes of Engineers like Torroja and Nervi. The lessons learned from these failures informed their answers.

9 CONCLUSIONS

The number of topics that could be considered essential for civil and structural engineers continues to increase and it is recognized that it is not feasible for engineering students to cover every possible subject in detail. The result is competition between programme areas for space in the teaching curriculum. Unfortunately, this can be an obstacle to including specialist topics such as construction history in dedicated modules. The general understanding is that such specialist topics can be taken at postgraduate level.

Modern engineering curricula are developed, at least in part, with a view to achieving the learning outcomes specified by accreditation bodies. These accreditation criteria require students to be able to demonstrate the ability to make decisions in situations where they do not have complete knowledge and to demonstrate an understanding of engineering practice and of how the engineering profession interacts with society. A course of study in construction history can be a particularly effective introduction to these aspects of engineering culture. This is a key justification for including the study of construction history in the curricula of engineering degrees.

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History of Construction Cultures – Mascarenhas-Mateus & Paula Pires (eds)

RBL through analysis of the development of high-rise buildings in Mexico City (1900–1952)

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ABSTRACT: Construction History may serve as a tool in order to enable architecture and civil engineering students to learn from past experiences. Considering this premise, through the Research Based Learning method and analysis of six iconic high rise buildings designed and constructed in Mexico City along the first half of the 20th century, architecture and civil engineering students will understand how the interrelationships among new materials, structural systems, seismic and soil mechanics (applied in Mexico City's Building Code) allowed Mexican architects and engineers to construct taller buildings in the city.

> "…universities should treat learning as not yet wholly solved problems and hence always in research mode."— Wilhelm von Humboldt on the future University of Berlin (1810)

1 INTRODUCTION

The History of Construction has broadly been left out of Architecture curricula and especially bachelor Engineering degree; with the exception of Professor David P. Billington's method applied through his class in "Structures in the Urban Environment", which has in any case not been extensively disseminated.

This situation disregards the knowledge able to be learned through the study of the experience and appropriate decisions taken to construct buildings that, in some cases, still exist after long periods of time.

Taking into consideration this premise, and having noticed there was no publication that summarizes the history of materials, structural systems, and building codes in Mexico over the first half of the 20th century; and how the interrelationship between these factors fostered the construction of high rise buildings in Mexico City, the research project named "Evolution of Construction Systems and their Repercussions on Built Objects" was proposed and approved and obtaining a development grant from the National Autonomous University of Mexico.

From the research project results, the course "Analysis of Contemporary Construction" for undergraduate and graduate students was designed and implemented, proposing the Research Based Learning Method as the central pedagogical strategy that students should apply. To understand this proposal, we first need to explain the research project that led to this course.

2 RESEARCH PROJECT

Building in Mexico City has always been a challenge; Mexico City's subsoil is filled with light, flocculent structured clay that produces local settlement differentials. As a seismic zone, this results in complex behaviors over long spans and in high rise buildings. The development of subsoil studies and foundation solutions, seismic engineering with analysis of the dynamic behaviors of structures, and the subsidence effect because of underground water extraction are important dimensions of relevance to every engineer and architect constructing in the city.

The research project was based on case studies considering the main topics mentioned above: subsoil conditions, foundation solutions, differential settlements, and seismic analysis of the building.

Six tall buildings constructed in Mexico City between 1900 and 1950 were selected: the Main Post Office (1902–1907), the National Insurance Building (1930–1932), the National Lottery Building (1933–1946), the Latin-American Insurance Building (1948–1956), the President Alemán Urban Center (1947–1949) and the Science Tower Building (1950–1952) at the National Autonomous University-Main Campus.

During the first half of the 20th century, these structures introduced the most advanced technologies and scientific knowledge imported from Europe and the United States and refined later in Mexico. Other features considered in their analysis were their construction materials, structural systems, building codes, and their contribution to the civil engineering and architecture field, with an innovative design.

The Diaz Government (1854–1920) had the primary objective of building iconic buildings to show to the world Mexico's modernity. Building materials, construction technology, and structural design recommendations came from France and the United States.

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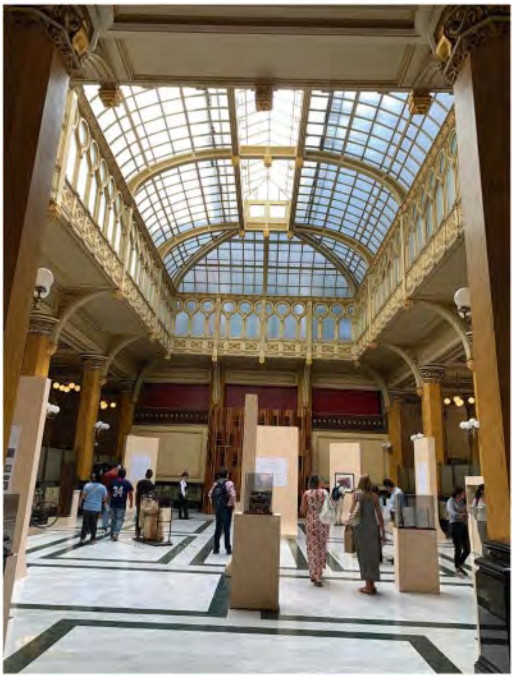

Figure 1. Mexico City Main Post Office central courtyard. (190–1907).

During this period, the first tall building was the Main Post Office (1902–1907) designed by Adamo Boari in Mexico City, proposed as the first case study (Figure 1).

This building was constructed with steel frames using the "Skeleton Construction System" (the structural system used for high rise buildings in Chicago and New York) imported by the structural designers and construction firm of Milliken Brothers of New York. This six-level building used Roebling's Fireproof system and a steel grillage system foundation (considering a soil compressive capacity of 5 t/m^2). All the structure was designed by the Mexican engineer Gonzalo Garita, applying the American methods for iron and steel structural design. When this oeuvre was built, it was the tallest building in Mexico City and the country (Santa Ana 2020)

This considered the building's architectural style as this derives from the construction method; with its eclectic style and plaster cast ornaments having created an iconic building that still functions today.

The first building code for the city was published in 1920, containing regulations for the city's growth and incorporating certain architecture solutions. "La Nacional Building" was the second tallest building constructed in the city in 1930. This skyscraper was the property of the American insurance company, The National Insurance Company, which in 1901 hired the architects Monasterio and Calderón to design this 13 story building. The foundation solution was wood point bearing piles below a two level box type. The wood piles were imported from the United States while the concrete was produced in Mexico for the first time. The building has steel structural frames and concrete slabs; all the steel structures are protected with reinforced concrete.

In 1933, the National Lottery Building started construction. This building takes an irregular shape, with a 66m high central tower that comprises 20 floors, making it the third tallest building in the city. It was entirely manufactured with national building materials. Its importance stems from the foundation solution; engineer Jose A. Cuevas used a floating foundation for the first time in the country. The height of the building and its form were planned to ensure a good foundation behavior. Its structural system consists of steel frames and trusses with concrete floors. This building was also the first to consider a seismic design, using the expressions proposed by the UBC of 1927 in its appendix and the Sieber-Cancani acceleration scale (Cuevas 1926).

The Latin-American Insurance Company (Latinoamericana de Seguros) hired architect Augusto Alvarez and engineer Adolfo Zeevaert to construct the first tall building in Mexico and Latin America. The Latin-American Insurance Company Tower started construction in 1948 with a studied architectural solution that considered the structural system and foundation solution to build a safe and long-term building. The foundation is a floating raft with a concrete box and 361 Button Bottom concrete piles driven into firm sand layers. According to the Bethlehem Steel Company, which fabricated the steel structure, its structural system of steel frames has sections more massive than those used for the Empire State Building. The structural design considered the American Construction Institute norms and wind pressures. Dr. Leonardo Zeevaert made the first dynamic seismic analysis on this building, and its seismic behavior helped transform later building codes, making newer constructions capable of coping better with earthquakes.

Contrary to what usually happens, this building's architectural design was ruled by the structural and seismic design, which resulted in a regular and symmetrical architectural plan.

The last two study cases, the President Alemán Urban Center (CUPA) and the Science Tower Building, were chosen because they represent a turning point in the tall building construction history in Mexico City. Both buildings reflect how the cement and steel industry got established and grew in the country, making reinforced concrete a preferred material and structural system (Figure 2).

Their construction process was cheaper as a less specialized workforce was needed for their construction. The CUPA represented a new way of living in Mexico City, dwelling in an apartment tower inside a big housing complex. Le Corbusier used this theory in the Unité d'Habitation de Marseille (1939–1952), being reinterpreted by Mario Pani in this design.

In this housing complex, six buildings of thirteen stories were built with a structural system of reinforced concrete frames and flat slabs cast in place (Pani

Figure 2. Latin-American Insurance Company Tower (1948–1956).

1950). All the facilities were modulated according to the construction materials used, allowing the tectonic of concrete and brick to create its aesthetic. This modular design helped economize the construction cost; reductions in the construction budget also allowed for infrastructure such as a swimming pool.

Figure 3. Miguel Alemán Urban Complex (194–1949).

The last case study, the Science Tower Building at the National Autonomous University Main Campus, represented its modernity. It was a 15-floor high rise building, built with a reinforced concrete skeletal structure that incorporated 6.10 m by 4.50 m spans. The first-floor columns present a 60 × 90 cm section, while the column section is 30 × 30 cm on the top floor. This building was the first tall building erected with a reinforced concrete structure; it was the second building to be seismically analyzed via a dynamic method. It is still in function nowadays (Figure 3).

Analysis of the case studies yields the following conclusions, among others:

- Each these buildings resulted from the nationally prevailing political and economic conditions.
- New technologies and knowledge were imported from the United States and Europe, allowing for construction with lighter materials such as steel, using it in skeletal structures that lowered the building's weight, avoiding building settlement via better foundation solutions.
- The foundation innovations used for tall buildings were later applied to design smaller-scale buildings constructed on highly compressive soils with high water ground levels.

These buildings reflect international trends in architecture, structural design, and the building materials used. The first four buildings were built with a steel skeletal structure, which was the predominant material and structural system globally, and used in Mexico until the late 1940s. In contrast, the last case studies represent the country's trend from the 1950s onwards, when concrete replaced steel in high rise building construction.

Different archives were consulted to obtain the building's information. These archives are the National General Archive of Mexico, the Historical Archive of the National Lottery, the Mexican Architects Archive of UNAM, and libraries where historical steel manuals and building codes were retrieved.

The results of this research and its conclusions determine that the structured analysis of a case study may have significant impacts and should be part of the engineers and architects training program. This conclusion was also supported by the undergraduate and graduate student observations during the research project.

Exercises with these characteristics would allow them to understand all the factors and elements needed for architectural, structural, and engineering design. In this way, the proposal for a particular course for architecture and civil engineering students took shape.

3 A RESEARCH BASED LEARNING COURSE

During the research project, undergraduate students were participants and monitored the results and their contributions to the project. They considered proposing a particular course for undergraduate and graduate students of architecture, civil engineering an excellent option as well as for other disciplines on the Architecture Graduate Program at UNAM.

For this course, a Research Based Learning (RBL) pedagogical methodology was selected as it has been reported to benefit student intellectual and personal development as it stimulates their interest in the discipline. Students thus become producers and coproducers of knowledge (Healey 2009) rather than passive recipients of Research.

3.1 *Research Based Learning principles*

Research Based Learning (RBL) may be defined as the nexus between the approaches of inquiry-based learning that represents "an approach to learning that is driven by process of inquiry" (Hutchings 2007). Also, a "research-based" context is how students learn through inquiry-based activities by actively pursuing an answer to a question (Neumann 1992).

The learning process is student-centred as they are motivated to take initiatives, propose routes of enquiring, and follow them. By these means, students develop intellectual capabilities such as critical thinking, reflection and self-criticism, independence, independent thinking, and information literacy. The process is accompanied and motivated by professors, providing support materials such as readings, videos, and previous research results.

Students discover how to research by engaging in practical examples. The inquiry process is in their ownership; hence, in RBL, the teacher must establish the context, space, and environment within which inquiry may best be stimulated to take charge of student learning.

There are four ways (Healey 2009) of engaging students with research:

- research-led: learning about current research in the discipline;
- research-oriented: developing research skills and techniques;
- research-based: undertaking research and inquiry;
- research-tutored: engaging in research discussions.

The factors making up RBL processes are multiple, variable, and open to selection. Different factors are involved and the student can determine the appropriateness, choice, and extent of the research process components. However, they should mainly identify critical issues, search for valid and relevant evidence, interpret and assess evidence, and present coherent conclusions (Hutchings 2006).

As an organic method, RBL does not provide a step-model or stages of the process that must be followed, striving to stimulate deep learning, and engender a spirit of engagement in students (Hutchings 2006).

3.2 *Course design*

As an organic method, RBL does not provide any step-model or stages in a process that requires following. As mentioned, the Research Based Learning focus falls on student learning and assessment in ways that parallel or mimic how research is carried out in the field.

The product may not be new knowledge per se but that is new to the students and transforms their understanding of the topic and the advantages of the research process. This also motivates student learning by undertaking the discipline's working practices and actively acquiring the principles of each subject.

Even though RBL does not apply a step-by-step method, as in the Problem Based Learning strategy, students are provided with some guidance steps divided into three sequential stages: foundation, intermediate learning, and self-authorship (Lopatto 2003).

The first level of activities proposed to students are: reading the scientific literature, learning to consult archival materials, envisioning the state of the art, designing a research project according to the tutor proposed topic, working independently.

The intermediate learning actions include stating a meaningful research question; and establishing an initial proposal of expected results.

The self–authorship stage includes:

- Production of significant research findings,
- The opportunity for oral communication, and
- The opportunity to develop a written communication, leading to a final report for assessment.

In accordance with these three stages, an eight-session course, held fortnightly, was designed, proposing to deploy Research Based Learning by applying

Figure 4. National Lottery Building (193–1946).

the case study example in order to help students simplify the research universe. As mentioned above, this case study would be complementary to the Research Project "Evolution of Construction Systems and their Repercussions in Built Objects," and thus the course applies the same analysis methodology.

Each student selects an iconic contemporary building constructed in Mexico City that is then analyzed throughout the course according to the following different aspects for each building:

- Mexico City's Building Codes.
- Construction Materials.
- Mexico City's urban expansion.
- Soil mechanics and foundation solution.
- Seismic design and building behavior.
- Architectural movements and styles.
- Systems engineering.

In order for students to make significant learning progress, one new theme is analyzed and discussed in each session. The discussion is based on research papers, videos, and web pages provided by the tutor. To determine student grades, they produce an essay that is presented to the class.

This knowledge is reviewed in each session through a set of questions, which ensure students augment connections to other learning in their long-term memory and enables tutor awareness over which materials need reteaching (Figure 4).

In the first part of the lesson, the discussion relates to the subject in general. The second then debates how different aspects (soil, construction, etc.) affected their case study's architectural and civil solutions. The final part of the session is dedicated to a general discussion among all students and the conclusions obtained from the different buildings they are analyzing.

Figure 5. Science Tower Building (1950–1952).

As part of each session's requested activities, students deliver an essay to analyze and provide conclusions for the designated topic. A second paper is then submitted studying the building aspect as applied to their case study.

Therefore, as the course progresses, students develop their research, achieving cumulative knowledge, and shaping their final paper. Furthermore, for analysis of each case study, students should mainly research the primary sources found in the Libraries or Archives of UNAM's School of Architecture and seek to obtain original research material.

The course assessment includes a final paper in which all the aspects reviewed throughout the course are included in the analysis of the building chosen by students as their case study.

However, as part of the educational strategy, this includes a process assessment approach. Students can deliver their modified work several times after receiving feedback from the tutor, with the student responsible for the final grade obtained.

In the first session, a syllabus is presented featuring the objectives, methodology, bibliography, and assessment. Additionally, this document sets out the organization of each session and lecture. The bibliography includes a final copy of the research project; thus, students can use this as a reference and model for developing their research (Figure 5).

As an additional factor for their research project, a student timeline is proposed for observing their building's interrelationship with construction history in a graphic format.

This course is still a work in progress as it has only been taught on two occasions in the last two years. Nevertheless, preliminary conclusions obtained from a student focus group have shown that their awareness of the interrelationship between architecture and engineering has been one of the critical learnings obtained. One of the students mentions that he had never realized all the aspects that should be considered when designing and constructing a building. Another indicated that he had never realized how the evolution of materials has changed the structural systems and how that in turn modified the shape and size of buildings.

4 CONCLUSIONS

The History of Construction could be a great asset in the education of Civil Engineers and Architects, learning from past experiences and knowledge. Unfortunately, its potential has not hitherto been valued for inclusion on curricula.

For civil engineers and architects, the History of Construction seems something remote that cannot be applied to actual experiences but, on the contrary, the lessons to be obtained could be extrapolated to resolve contemporary problems.

Mexico's lack of a comprehensive study of the evolution of construction materials, structural systems, and their impacts on architecture solutions justified this research project. The research and analysis of the history and development of building materials and how they transform the foundation and structural systems used in designing and constructing new buildings in Mexico City in the first half of the 20th century are the basis for innovative solutions applied to tomorrow's buildings.

Six iconic tall buildings were analyzed through different aspects of their design: architectural features, foundations, structural systems, engineering systems, and building codes, which allowed students to understand the effects of these transformations. This research project demonstrates the potential for introducing students to the research field in an idea serving as the inspiration for designing a course that applies History of Construction and Research Based Learning as pedagogical tools that allow for grasping how a structural and foundation system works in an already constructed building.

Engaging students in research is the most effective way to help students begin thinking like engineers and architects, which is arguably one of the core graduate attributes for most discipline-based degree programs (Healey 2005).

Research based education for undergraduate and graduate students makes them think broader and from a wider perspective. Engaging students in scientific investigation foster their ability to think critically and develop cognitive skills such as critical thinking and problem-solving skills. This ability allows students to gain both deeper insights and understanding of topics and aptitudes for problem solving in their professional careers.

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History of Construction Cultures – Mascarenhas-Mateus & Paula Pires (eds)

The role of construction history in safety assessments: A case study of reinforced concrete "Gerber" bridges in Italy

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ABSTRACT: In Italy, in 2016, the collapse of the Annone Brianza overpass revealed an inherent vulnerability of half-joint reinforced concrete bridges. On 6 May 2020 the National Ministry of Infrastructures and Transport approved the new "Guidelines for risk management, safety assessment and monitoring of existing bridges": the document list Gerber bridges as critical structures and highlight the importance of "an accurate investigation of the technical and administrative documentation of the existing bridges". In this paper, Italian case studies on Gerber reinforced concrete bridges are traced from the very first use of this bridge typology to the analysis of current deterioration phenomena occurring in the existing structures. The reported case studies highlight the crucial role of construction history investigation in the preservation of infrastructural heritage.

1 INTRODUCTION

In Italy in 2016 the collapse of the Annone Brianza overpass showed an inherent vulnerability of half-joint reinforced concrete bridges. On 6 May 2020 the National Ministry of Infrastructures and Transport approved the new "Guidelines for risk management, safety assessment and monitoring of existing bridges" (Italian National Ministry of Infrastructures and Transport, 2020). In addition to the procedures and tools corresponding to the general purposes of this document, it identifies critical issues related to different bridge structure typologies. In particular, it provided a detailed classification of "critical elements" (i.e. those bridge parts that are particularly subject to degradation phenomena and whose possible malfunctions can significantly affect the overall structural behaviour of the structure). These elements include Gerber girders in reinforced concrete bridges, requiring a mandatory and urgent general safety assessment of the structure of Gerber bridges. The topic, underlined by the Italian code, is addressed by recent international research (Desnerck et al. 2018).

The internal steel reinforcement layouts of the Gerber joints do not comply with current design practice and codes; moreover, Gerber joints are difficult to inspect and, due to their shape, they are particularly subject to water infiltration. The Guidelines highlight the importance of "an accurate investigation of the technical and administrative documentation of the existing bridges" in order to acquire the knowledge necessary for any conservation project regarding both the chosen design and construction procedures and the transformations of works during their useful life. The cited document highlights both the importance of the role of the historical research in the monitoring and preservation of existing bridges emerges and the urgent need to focus analysis on the remaining reinforced concrete Gerber bridges on Italian territory.

This paper presents the results of the construction history-based survey addressing the safety assessment of existing Gerber bridges.

In the disciplinary framework of enhancing cultural values of infrastructural heritage in maintenance operations (Pelke & Brühwiler 2017), the analysis focuses on the introduction and diffusion of this structural typology in Italy and on the listing and classification of existing Gerber bridges; then, recurrent degradation phenomena are identified and discussed through literature dedicated to maintenance interventions. The case studies of the Magliana bridge and the Marconi bridge on the Tiber in Rome are discussed in detail.

2 FIRST APPLICATION AND DEVELOPMENT OF THE STATIC SCHEME

The progressive introduction of the static scheme of the cantilever beam (cantilever bridges) was developed with the intention of transforming the continuous beam on several supports into a statically determined system through the introduction of a strictly indispensable number of hinges. The solution permitted simplification of calculations, optimization of stresses on the structural elements and compensation of vertical failure whilst developing construction processes without falsework.

The scheme of the cantilever bridge, which had been systematically developed in the 19th century, with the rise of iron and steel as construction materials, dates

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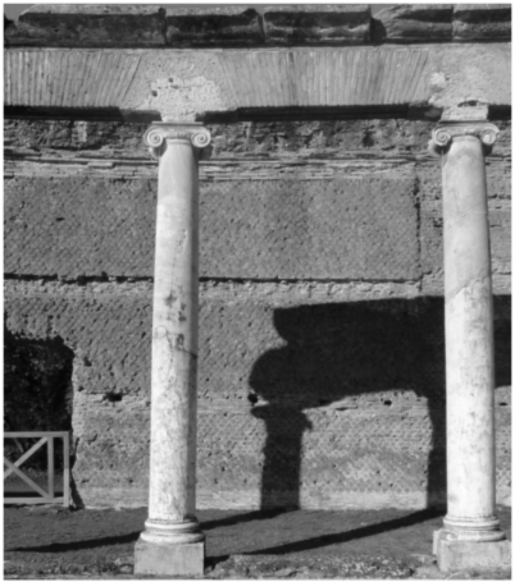

Figure 1. Maritime Theatre at Villa Adriana (courtesy of G. Cinque).

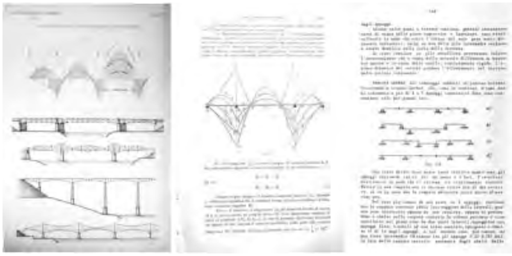

Figure 2. Gerber patent (1866) and Italian bridge design manuals.

back to ancient times. Bridges that follow the cantilever principle have been used in tropical countries since prehistoric times (Steimann 2011). The lintel with disconnections is also witnessed in Greek and Roman architecture, for example in the forum of Pompei or in the Maritime Theatre at Villa Adriana (Di Pasquale 1996) (Figure 1), where the architraves, consisting of a single wedge-cut or brick element, were supported by large stone cantilever capitals; this rather empirical adopted solution was probably due to the need to avoid cracking in the architrave following subsidence of the foundations, as well as to facilitate the construction procedure of these structures by breaking the architrave into several blocks. As noted in the literature (Wilcox 1898, Mehrtens 1900, Panetti 1900, Timoshenko 1983, Steimann 2011), the development and systematization of this bridge typology took place in the second half of the 19th century.

In 1811, Thomas Pope in his "Treatise on Bridge Architecture" had already proposed the adoption of a hinge-cut scheme for a bridge over the Hudson and, in 1833, the construction of a cantilever-type bridge in Paterson (New Jersey) by M. A. Canfield was attested in (Wilcox 1898). Then, between the 1840s and the 1860s several engineers (Fairbairn, Clark, Ritter, Culmann) tried their hand at the subject, obtaining substantial theoretical and design solutions. The scheme, already known as a cantilever bridge, *portes à faux* in French, took the name "Gerber girders" from the German engineer Heinrich Gerber (1832–1912), in the 1860s. Although it was not always mentioned in the treatises of the time (Wilcox 1898), Gerber was nonetheless recognized as the author of the first bridges built with this static scheme: the bridge over the Main in Hassfurt (1867) – in which the central span beam was placed on the two lateral cantilevered beams by means of hinge joints – and the Sofia Bridge in Bamberg (1867). The system (Figure 2) was patented in 1866 (Gerber 1866).

In 1877, Charles Shaler Smith (1836–1886) built the Kentucky viaduct, the first large-span cantilever bridge in America: in this structure and in the subsequent Niagara viaduct built in 1883 by Charles Conrad Schneider (1843–1916) the assembly of the beam was carried out without fixed scaffolding. The names of the two American viaducts identified the types that classify the construction procedures without falsework which were later adopted for the construction of structures of this type. In 1889, the opening of the Forth Bridge on the Firth of Forth, by John Fowler (1817–1898) and Benjamin Baker (1840–1907), marked the end of the experimental period of this structural typology and its definitive systematization for large span metal truss bridges.

At the end of the century the Gerber bridge developed in numerous schemes, "some with the appearance of arched trusses, others with that of suspended bridges, to form a multiform family, which retains this very distinctive character: the use of trusses consisting of trunks protruding cantilevered from the supports" (Panetti 1900).

3 INTRODUCTION IN ITALY

In Italy, the Gerber bridge entered engineering practice late; this was testified to by the well-known and widespread *Manual of the Engineer* (Colombo 1877) edited by engineer Giuseppe Colombo (1836–1921) from the first edition of 1877 to 1917, the year in which it was entrusted to other colleagues (Azimonti et al. 1919); still, in the 1926 edition of this Manual, the Gerber beam was not included in the chapter dedicated to structural schemes.

In 1886, Camillo Guidi (1853–1941), in his "Lectures on Graphic Statics", mentioned the "continuous beam with hinges" (Guidi 1887). In 1904, Guidi dedicated a paragraph of his lectures on "Bridge Theory" to the Gerber girder, highlighting the possibility of obtaining with this scheme the same economic convenience of the continuous beam (Guidi 1905). In 1905, Antonio F. Jorini (1853–1931) dedicated chapter VI

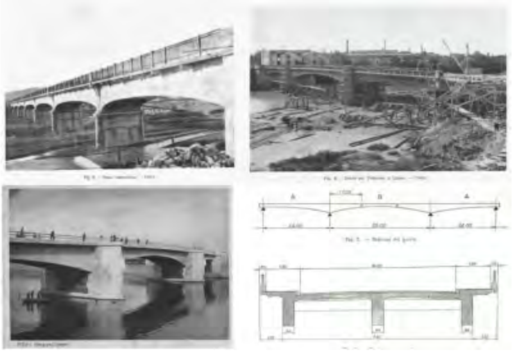

Figure 3. Gerber bridges in Italy, 1932–36 (Ferrobeton 1933–48).

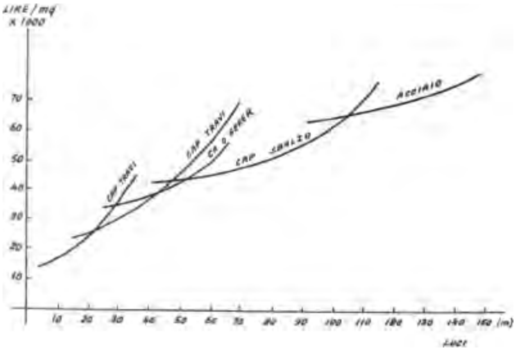

Figure 4. Diagram showing the application of Gerber scheme to cast in situ ordinary reinforced concrete bridges (Rinaldi, 1974).

of his manual "Theory and Practice of Bridge Construction" to "continuous beams with hinges". In the manual, where the calculation of a three-span beam, with two hinges in the central span, was illustrated, the convenience of introducing hinges into the continuous beam schemes was defined because "with the choice of the number of hinges, and their position in the continuous beam, it is possible to obtain a statically determined structure, in which the internal stresses are independent of the vertical movements of the supports" (Jorini 1905). The author also pointed out "the possibility of mounting the trusses with false systems, without the help of service scaffolding" (Jorini 1905).

In Italy, given the limited development of large-span metal viaducts at the end of the 19th century (Nascè 1982) when compared to other industrialized countries, the spread of Gerber-type bridges was directly due to the introduction of reinforced concrete.

In 1930, Giuseppe Albenga (1882–1957) in chapter V of his "*Lezioni di Ponti*" (Lessons on Bridges) reported the convenience of adopting hinged patterns in continuous reinforced concrete trusses. "Introducing as many hinges as there are superabundant support conditions", with the warning "not to drop more than two hinges between two consecutive supports and not to have more than two supports between two successive hinges" (Albenga 1930). In the Manual, there are no examples of Gerber bridges in reinforced concrete built in Italy, but the "very frequent use in reclamation areas" of cantilevered beams is mentioned, in particular for "three-span schemes characterized by two intermediate piers and small cantilevered bank spans" (Albenga 1930). On the other hand, not even the two editions, published in 1924 and 1932 respectively, of the "Ponti in cemento armato Italiani" manual by G. Santarella and E. Miozzi, reported built examples of Gerber bridges (Santarella & Miozzi 1924, 1932). In 1933, the catalogue of Ferrobeton – at the time one of the main Italian companies active in the sector of reinforced concrete construction – reported the construction of the following bridges known as Gerber-type girders: the bridge over the Amendolea river in Calabria; the bridge over the Leira torrent in Voltri and the bridge over the Volturno in Capua (Figure 3) designed by the engineer Giulio Krall (1901–71).

Only in 1953, when Albenga published an updated edition of his "*Lezioni di Ponti*" (Albenga 1953) reporting greater dissemination of the typology also for large-span bridges, were examples of reinforced concrete Gerber bridges built in Italy cited: the bridge of the Empire over the Arno in Pisa, designed by Krall (1901–71) and built by Ferrobeton himself in 1936 (Krall 1937); and the Belvedere overpass in Vercelli, designed by Antonio Giberti (1883–1963).

The diffusion of the typology was also testified by the updated edition of the same Albenga manual, dedicated instead to theory (Albenga 1958): the third chapter was entitled "the simple beam and the Gerber beam", testifying the dissemination of the latter structural typology for reinforced concrete buildings.

In 1974, Giuseppe Rinaldi in his manual *La costruzione dei ponti* (Rinaldi 1974) reported a series of economic considerations on the use of different types of reinforced concrete bridges, in the light of the development of the freeway network (1956–73): even if "recently Gerber type bridges have been carried out with positive results", there was an overall decrease in the application of this static scheme (Figure 4). The Gerber girder, considered more suitable for casting, was regarded as ideal for spans within 65 metres and "limited for higher spans by the costs of centering" (Rinaldi 1974).

4 FOR A CENSUS OF THE EXISTING GERBER BRIDGES IN ITALY

On Italian road bridges, the existing reinforced concrete Gerber bridges were mostly built between the 1930s, as in the rest of Europe (Legat et al. 1948), and the 1970s. In Italy, the static scheme spread first in the autarchic period (1936–40), as the most suitable for material savings according to the easy calculation, and later during the reconstruction after WWII and the

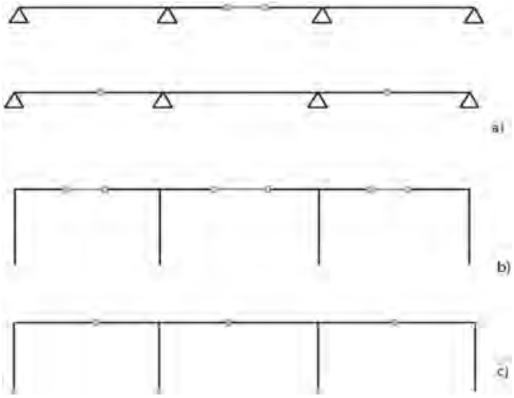

Figure 5. Sketches of the major static schemes adopted for Gerber bridges built in Italy (the authors, 2020).

development of the national road network of the 1950s and 1960s.

Italian Gerber bridges feature a remarkable morphological variety and can be classified according to the three static schemes reported in Figure 5. The first scheme represents an articulated girder with multiple supports: considering the general principle that a Gerber girder must have as many hinges as there are intermediate supports, an articulated girder is placed between the two overhangs (internal hinge – Niagara Type) or between the central piers and the abutments (external hinge – Kentucky type) (Figure 5a). The second diagram describes a sequence of cantilevered piers and suspended span (Figure 5b). The third scheme describes a sequence of multiple statically determinate frames (Figure 5c).

The first scheme (Figure 5a), was widely adopted for the construction of ordinary roads and urban bridges built mainly between the 1930s and the 1950s with exclusive use of reinforced concrete cast in situ. Some significant examples were among the first bridges featuring this static scheme: the aforementioned bridge over the Arno river in Pisa, rebuilt by the same construction company Ferrobeton in 1947; the Magliana bridge over the river Tiber in Rome (1938); and the Marconi bridge over the river Tiber in Rome (1939). The second scheme (Figure 5b) was mainly used for the construction of highway bridges built in the 1960s. Also taking advantage of the more widespread industrialization of the building sector and of the pre-stressing technique in reinforced concrete construction, these bridges feature prefabricated suspended spans and cantilevered piers cast in situ. Noteworthy examples of this typology are: both the Rio Sanda bridge over the Teiro bridge on the Voltri-Albissola highway (1955) and the Settefonti viaduct of the Autostrada del Sole highway (1959), entirely featuring the use of Innocenti scaffoldings supporting the cast; and the Colle Isarco viaduct for the Brennero highway (1962), depicted in Figure 5 and instead characterized by the combined use of the cantilever construction technique, pre-stressing systems and prefabricated elements (Gentilini 1970).

Figure 6. Colle Isarco viaduct, 1962 (courtesy of the Fondazione Gentilini); Velino viaduct, 1963 (Zorzi 1963); Niagara viaduct, 1895.

On developing the same optimization goal of the execution of avoiding falsework, the third scheme (Figure 5c) representing a sequence of multiple statically determinate frames was in the viaducts designed by engineer Silvano Zorzi (1921–94) (Iori & Capurso 2019). Noteworthy examples of these are the Stura viaduct of the Turin-Savona highway (1968–70) (Zorzi 1970) and the Poala viaduct at Veglio Mosso (1972–73) (Zorzi 1974). While it is true that, from the construction site point of view, the adoption of this static scheme resulted once more in the effectiveness of the Gerber bridge that had driven its rapid evolution in the 19th century (Figure 6), on the structural level today this scheme proves to be completely devoid of the recent concept of “structural strength” (NTC 2018 2.1).

In addition to the types mentioned, Gerber girders were even adopted for special works, such as the bridges designed by the engineer Riccardo Morandi (1902–89). In his research on “balanced structural systems”, Morandi relied on this bridge typology several times. It was used for both the project of articulated girders on multiple supports – as in the case of the Quercia-Setta viaduct on the Autostrada del Sole (1957–58), which also featured prefabrication of the elements forming the suspended span (Morandi 1967) – and the conception of special schemes, such as cable-stayed bridges (i.e. the existing Carpineto viaduct (1976) on the Basentana road (Morandi 1977)).

4.1 *Common aging and deterioration phenomena*

Evident signs of deterioration emerged quite early compared to the time of construction of reinforced concrete bridges and have amplified notably over time. In addition to these evident aging-related causes, the arrangement of the secondary reinforcements in the cantilever extremes, designed according to the calculation code of the time period (1930s–1960s), were

Figure 7. Detail of deterioration in supporting device and reinforced concrete half-joint (courtesy of Rome Municipal Archive, Bridge Office and Micheloni et al. 2018).

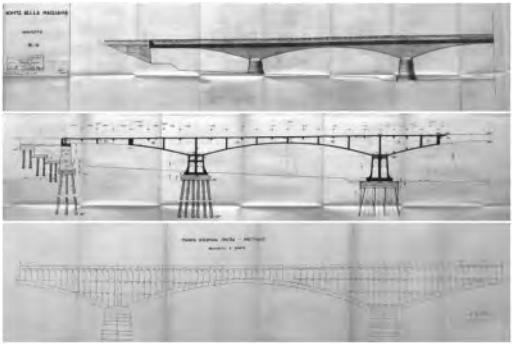

Figure 8. Magliana bridge, 1939 (courtesy of Rome State Archive).

judged "incorrect" from 1992 (CNR, 1992, 10037/86) onwards, when the STM was ruled under the Eurocode 2 (EN 1992-1-2:2004), this arrangement is, thus, considered as a crucial cause of structural vulnerability of for existing Gerber bridges (Desnerck 2018).

The vulnerability of Gerber schemes has numerous aging time-related causes. Most of them are common issues for reinforced concrete structures, such as the natural aging of the materials (with particular regard to the joints), the phenomena of carbonation of concrete with material detachments, the onset of oxidative phenomena in the steel and the consequent formation of cracking states, and the change in loading conditions. Others are, instead, specifically related to the Gerber bridge half-joint shape: leakage of water through the joint causing deterioration of the concrete and corrosion of the reinforcing steel and errors during execution, such as misalignment between the cantilever extremes, are very common (Figure 7). Furthermore, even half-joint elements, placed on the protruding nib of the structural element, are particularly subject to premature aging, causing dangerous discontinuities in the road surface that, due to even contained disruption, alter driving comfort. In the context of this joint deterioration phenomena, it is necessary to understand how Gerber half-joints were built in Italy and whether it is possible to trace the adoption of some recurrent details or solutions. In executive practice, indeed, the use of metal devices (hinges, pendulums, rollers) derived from metallic construction practices was combined with the extensive use of lead sheets, steel plates and the design of special reinforced concrete pendulums devices (Cestelli Guidi 1949, Malerba 2018).

5 TWO BRIDGES IN ROME

Insight into the two bridges located in Rome, which were among the first Italian examples of Gerber bridges in reinforced concrete proved useful to illustrate specific deterioration phenomena in relation with the construction history of the two bridges. The two case studies feature many common aspects: both bridges were designed according to urban planning of the Universal Exhibition of 1942 (E42), conceived during the fascist regime and not opened due to World War II. The two structures also adopted a similar static scheme of suspended span on a half-joint. In both case the decks feature a movable part in the central span enabling navigation of the river. Furthermore, the two bridges have a very similar history: the late 1930s design and construction sites opened in 1938 and suddenly interrupted by WWII, closing only in the mid-1950s. The deterioration phenomena, observed in the two bridges, can be attributed to different causes, mostly linked by the general lack of both adequate knowledge of the two structures and a maintenance programme.

5.1 *The Magliana bridge*

The Magliana bridge was designed by engineer Carlo Cestelli Guidi and the architect Cesare Valle between 1937 and 1940 in the framework of the urban planning for the E42. Unlike the first design hypothesis which envisaged a five-span bridge, the final project, approved after the opening of the construction, was a 255.80-meter-long structure, with seven spans, featuring a curved intrados profile of the girders and 12-meter-long movable steel girders placed in the central span (Figure 8). After WWII, during which the bridge was seriously damaged, works restarted in 1946 and the bridge was, finally, completed and load-tested in 1950. The deck, supported by box-shaped piers, consists of five longitudinal ribs stiffened transversely and completed with a horizontal slab. The two lateral spans feature Gerber half-joints (Figure 8). The fixed joint equipment was made of lead plates, the rollers with metallic devices, while the pendulums were built in reinforced concrete. A travertine plate coating features in all the structure, except the girder intrados.

In 1976, after 26 service years, according to evident signs of deterioration, the structure was subjected to an investigation. Despite the change in the hydraulic

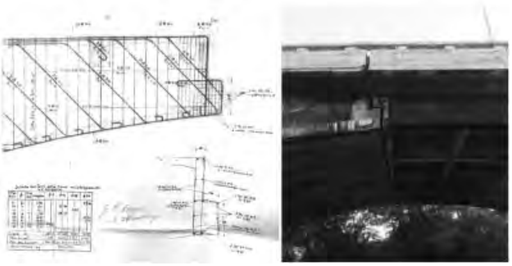

Figure 9. Magliana bridge reinforcements details, 1939 (courtesy of Rome State Archive) and picture of the half-joint, 2020.

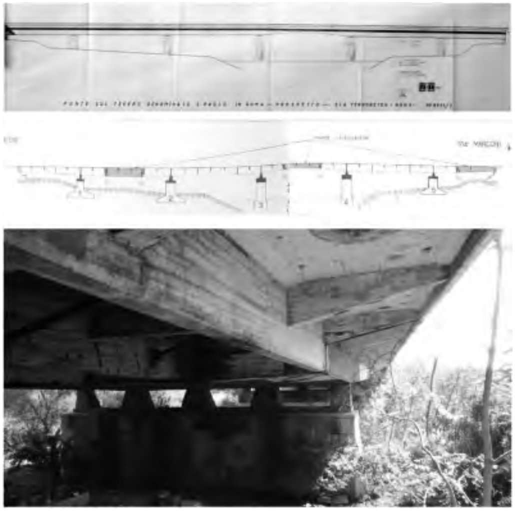

Figure 10. Marconi bridge, 1950–74 (courtesy of Rome State Archive).

regime of the river with respect to the project hypothesis, the consequent lowering of the piers was considered negligible and the bridge structure appeared overall to be in a good general state of conservation. The attention of the engineers entrusted with the investigations was focused on Gerber half-joint: the local presence of cracks and a "macroscopic expansion between the faces of the joints and the fully visible deterioration of the metallic joint equipment" were reported as major effects of the aging of the structure. In particular, the metal cylinders of the rollers were highly deformed, corroded and blocked by the presence of other materials. The joint equipment was, thus, replaced and the central opening deck was covered with a reinforced concrete slab, removing its original function. Similar problems arose 40 years later. Further investigations were carried out in the years 2017–18. In the global decay of the structure and its travertine coating, the Gerber half-joint appeared to be severely damaged: the novel shaped lead plates had not contained displacement between the joints within the correct limits; consequently, the damage was advanced, albeit to a lesser extent but such as to make it significant. Furthermore, the mortar of the support appeared disjointed so as to move the support axis and deform the support itself.

In both of the two maintenance interventions, no historical investigation regarding the construction material and details or calculation reports showing the rebar arrangement and dimensioning (Figure 9) were taken into consideration in the maintenance design as comparative terms for the in-situ surveys. The main cause of the damage was identified in the inefficiency of the rainwater run-off system and in the continuous water leakage through the joint.

5.2 *The Marconi bridge*

Several reasons can be found for the damage of the G. Marconi Gerber bridge over the river Tiber in Rome, designed by the engineers Guido Viola (1895–1984) and architect Giuseppe Samonà (1898–1983).

Construction started in 1938 after the competitive tender was awarded to the Vitali company. Work was interrupted in 1941 when only the foundations and the piers had been built. The construction of the deck started in 1950 and was completed only in 1955 by the Ferrobeton company and engineer Krall. The bridge, originally designed as a five-span girder bridge, was transformed into a six-span structure during the construction phase: the deck, 32 metres wide, rests on five piers, two of them in the riverbed, and on two terminal abutments, for a total length of 228 metres. The second bay, the fourth and the sixth feature half-joint suspended beams. The deck structure consisted of five longitudinal ribs strengthen by a cross element and lower and upper slabs. The three suspended beams are 18 metres long consisting of five longitudinal ribs strengthen by a cross element and an upper slab (Figure 10). Supports were designed as high-strength concrete prisms fitted at the tops with metal plates in cylindrical profile (Figure 11).

Since the end of the 1960s, the bridge has been subjected to periodic monitoring due to "anomalous signs of deterioration of the structure in correspondence of the half-joint beams" (Leone, 1977). Initially attributed to the malfunctioning of the road joints that had been lost, the signs of deterioration in process of creased over time and were attributed to the deformations of the joint devices. In 1974, a widespread disintegration of the concrete of the Gerber joint with depressions of several centimetres occurred. An accurate analysis was then started and it was possible to specify the causes of the damage.

Despite the suspended beam, due to the concomitance of these conditions there was a series of small cracks, but the work was still structurally responsive to the functioning-loads; however, consistent differences between the design project and the ex-built structure were identified. In particular, the geometry of the half-joint was undersized compared to the one presented on the original design, thus reducing the contact surface:

	Years	Bridge name	Designer	Client	Firm	Archives	Picture	startic scheme
1	1932	Volturno bridge in Capua	G.Krall	Voltri Municipality	Ferrobeton	Voltri Municipality Archive		
4	1936	Ex Impero bridge over the river Arno in Pisa (re-built 1947)	G. Krall	Pisa municipality/ANAS	Ferrobeton	Pisa State Archive & ANAS Archive		
6	1948	Pescara bridge overe the Pescara river (reconstruction)	C. Cestelli Guidi	Pescare Municipality	Rotundi	Pescara Municipality Archive		
7	1949	Poggio Mirtetobridge over the river Tiber	C. Cestelli Guidi	ANAS, Roma	Ugo Allegri & C	ANAS Archive		
11	1954	Lerone viaduct, Voltri-Albissola motorway	A. Assereto, R. Antola	ANAS, Genova	Sugliani e Tissoni	ANAS Archive		
14	1958	Casalmaggiore bridge over the river Po	G. Borzani	Parma and Cremona Discrit	Fincosit	Parma District Archive		
17	1959	Quarcia Setta viaduct, Sole motorway	R. Morandi	Società Autostrade	Sogene	R. Morandi Found & Sogene Found, Central State Archive		
18	1959	Settefonti viaduct, Sole motorway	C. Castiglia, F. Levi	Società Autostrade	Edilstrade Ligure (brevetto BBRV)	Società Autostrade Archive		
19	1960	Eur lake bridges in Rome	E. Schmidt, G.Belloni	ANAS, Rome	Grassetto	ANAS Archive		
30	1971	Bridge over the Po river, Centro Padana motorway	B. Gentilini, L.Gentilini	Centro Padane Motorway	E. Romagnoli (BBRV)	Centro Padane Motorway Archive & Ing. Gentilini Foundation		
31	1972	Poala viaduct in Veglio Mosso	S. Zorzi, L. Lonardo, E. Faro	Ministry of Public works	CIS Compagnia Italiana Strade (Torino)	Vercelli Genio Civile Archive		

Figure 11. Extract from the census of Gerber bridges in Italy.

dimensions of the project were not respected in construction, and protruding nibs of the cantilever element were made with a size of 24–25 cm and contact area of only 18 cm.

Furthermore, the comparison between the in-situ survey and the original design drawings disclosed further "errors" in the construction phase: among these, the incorrect execution of the concrete casting corresponding to the roller supports compromised thermal expansion effects.

6 CONCLUSIONS

In this paper the Italian case studies of Gerber reinforced concrete bridges are traced as of the very first use of this bridge typology to the analysis of current deterioration phenomena occurring in the existing structures. The investigation discloses the inner critical issues embodied by the choice of this construction and structural solution, discussing the convenience of the adoption of this articulated structural system compared to the aging phenomena detected. In recent years, many specialized studies in the field of structural engineering have focused on identifying the specific causes of degradation and obsolescence, manifested in individual case studies (Malerba, 2018).

Considering the broad application of this bridge typology, a systemic approach to the problem of the safety assessment of these structures was attempted, in light of the evolution of the knowledge of the materials and of the calculation theory and codes (Desnerck 2016). In this research framework, this article supports the role that could be played by construction history culture in addition to traditional tool of structural engineering praxis such as diagnostic investigations, tests and modelling surveys.

While knowledge of the original project drawings together with the evolution of the design and calculation code provides clear and useful data for the elaboration of safety analysis, the construction site facts prove fundamental for the verification of any discrepancies in the execution phase of an individual work. In this sense, the two reported case studies of the Magliana and the Marconi bridge in Rome demonstrate antithetical approaches to maintenance projects. While the first one overlooks the historical investigation, the latter states the operational value of the history of construction as a knowledge basis for conservation design and causes of decay.

Furthermore, in the disciplinary perspective (Pelke & Brühwiler 2017), this paper argues that through construction history it is possible to undertake a census of Gerber bridges (Tab. 1) and, incorporating the causes of decay and the calculation code evolution, to establish the risk classes of existing structures, demonstrating the effectiveness of a construction history-based strategy in infrastructure heritage preservation.

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History of Construction Cultures – Mascarenhas-Mateus & Paula Pires (eds)

Problems of sources and bridges

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ABSTRACT: Where does the history of structural engineering fit into the great fresco of historiography? Who is the good historian of structures? What are that historian's sources? Are those sources "honest"? The collapse of the bridge over the Polcevera River in Genoa triggered a profound rethinking of historical research in the field of structural construction in Italy, briefly summarised in this contribution. The paper is an outcome of the Research Project SIXXI–XX Century Structural Engineering: the Italian Contribution, ERC Advanced Grant 2012, headed by Sergio Poretti and Tullia Iori from Rome Tor Vergata University.

1 INTRODUCTION

On 14 August 2018, the collapse of the bridge over the Polcevera River in Genoa triggered a profound rethinking of historical research in the field of structural construction in Italy. The bridge was one of the most iconic symbols of the Italian School of Engineering: it even inspired a construction game for children.

On the one hand, the many doubts about how the bridge collapsed imposed an urgent, scientific commitment to study and carry out precise historical research; on the other hand, the wide dissemination of SIXXI research results among students and professionals – who will inevitably be called upon to intervene in the future – was even more necessary. In Italy, the generalised unawareness of the value of structural heritage emerged from the debate after the collapse. The high level of building experimentation and the high average age of our bridges was not even known to those who had to preserve them. It was necessary to tell everyone about the cultural identity, the technical value and the historical significance of the Italian School of Engineering. This commitment, however, did not prevent the continuous brooding: relative to the way this research was carried out, so devoid of historiographical tradition.

2 THE ENGINEERING HISTORIAN

Is our research really historical research? And, if so, where does the history of structural engineering fit into the great fresco of historiography? In 2005, Sergio Poretti authoritatively included it in the history of construction. Poretti defined the history of construction as "the material history of architecture", quoting Eugenio Battisti who, in the 80s, indicated "the way of building" as "the new frontier of the history of architecture". Poretti recognised, however, that studies of 20th-century Italian structural engineering have never been part of the history of architecture, except marginally. When it happened that a historian ventured to deal with some engineer or bridge, he did so by remaining strictly external, looking from afar, without investigating the real built work, and without even trying to approach the other technical aspects of which that work is the consequence and that engineer is the interpreter: the evolution of scientific thought, techniques, materials, site solutions, regulations, and the lives of workers and companies. (Poretti 2005)

It's true that the history of structural engineering still needs an operation of essentially interpretative and critical synthesis that reconstructs the general picture, but this synthesis, as now consolidated in all the more mature historiographies, must be based on the "slow, patient accumulation of punctual investigations and specialist studies". These demanding, tiring micro-stories, however, struggle to find researchers interested in digging them out of the archives.

This is due to the usual old problem: the engineer is almost never interested in history, in the past. The engineer looks to the future. But training as an engineer, preferably a structural engineer, is indispensable to investigate the intricate carpentry of Morandi and Zorzi or to understand Musmeci's high mathematical reports (Figure 1).

The historian of structures must know how to distinguish a hinged joint from a fixed one, not because they find it written in the reports but because they intuit it from the geometry of the joint itself. In the designs of reinforcement rods, the historian distinguishes secondary reinforcement from prestressing cables and visualises the flows of energy, of opposite sign, flowing in a stay (especially when the steel tie rod is wrapped in a concrete sheet, prestressed by other cables). In the synthetic pages of calculations still carried out by hand, the perfect historian recognises the

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Figure 1. Photogram of the video of the collapse of the bridge on the Polcevera River, accidentally taken by a private camera, 14 August 2018 (SIXXIdata).

starting hypotheses, skips all the steps and understands the approximation of the conclusions. And, above all, they resist the temptation to redo the calculations using modern software: this is the most useless pastime for a historian (while it is a necessary exercise for those who have to verify and validate the current use of the structure – but this is another job!). The historian makes the effort to read the documents with the eyes of a pre-computer engineer, without judging the project with modern parameters. That is, they must renounce the actualization and "presentism" that often infect even traditional historiography. At the same time, the historian knows – and this is much more difficult – all the other stories: the history of the materials, of the construction site, of the companies, but also the political, economic and social history of the country where the work is carried out.

For this type of qualification, degree courses and related "Dublin Descriptors" do not exist. The training is entrusted to the few PhDs with dedicated scholarships, which must intercept and select this very rare figure of engineers interested in history. It takes a lot of luck!

3 THE SOURCES

Compulsory teaching for young, future historians should certainly be a branch of "Contemporary Diplomacy". What are the documents we are dealing with in historical research? Are they "honest", i.e. are they what they claim to be? And what do they really tell us? The dramatic events in Genoa have triggered a further reflection on this too (Iori 2020a).

The historical work I have carried out over the years has always had to do with peculiar documents that are rarely interesting for other research. Researching to study the history of reinforced concrete in Italy, for example, I examined the archives of patents from the origins to the Second World War. Not looking for this or that patent of a known author, but simply browsing through all of those pertinent to the construction technique. The history of the material has practically written itself. Yet the technique of reinforced concrete in Italy has not really been a sequence of commercial inventions. On the contrary: the material has instead been used very freely. But the variation in the density of patents dedicated to specific innovations has made the main steps in the evolutionary process evident. At first, in the pioneering phase, when the combined behaviour of steel and concrete was not yet clear, I found only privatives for fanciful designs of reinforcement. Then, when the technique stabilised around the Hennebique model, to lighten the floors, in Italy, pots were used: in this phase, the patent archive is full of inventions of pots of a thousand shapes. After the Messina earthquake of 1908, the filed patents only concerned anti-seismic frames. Finally, in the time of autarchy, designers spent all their energy to protect the inventions of alternative materials to steel to reinforce structures. Just before the Second World War, the first patents for tools to pull prestressing cables appeared.

The overview of patents that I lined up one after the other was really amazing. Perfectly unknown people, who had not played a role in the construction world, signed most of the inventions. Their patents have never been applied for in practice (Figures 2, 3).

Apart from the topic, which was very timely according to the historical context, many patents were mostly chimeras that could not be realised in terms of construction: e.g. houses hanging like laundry and therefore indifferent to the shaking earth; or the pots for the slabs, shaped like pieces of a puzzle, which, thanks to interlocking, should have become tensile strength, favouring steel savings. Patents are mostly dreams, even of paranoid people who, in order to protect their invention, do not talk about them to anyone, not even to those who can reveal the absurdity of their drawings in a few minutes. And yet, statistically, on the whole, they provide a very precise cross-section of the technological debate and the evolutionary path taken by the material (Iori 2001).

The patent is a peculiar document not only for this reason. The patents of Pier Luigi Nervi, so important for the history of the Italian School of Engineering, concealed more than they explained and generalised more than they specified. For Nervi, the patent served to protect rights, certainly not to reveal the recipe to those who wanted to copy the idea. Hardly ever do his patents help to precisely date the invention, because they were often filed after the first application, when

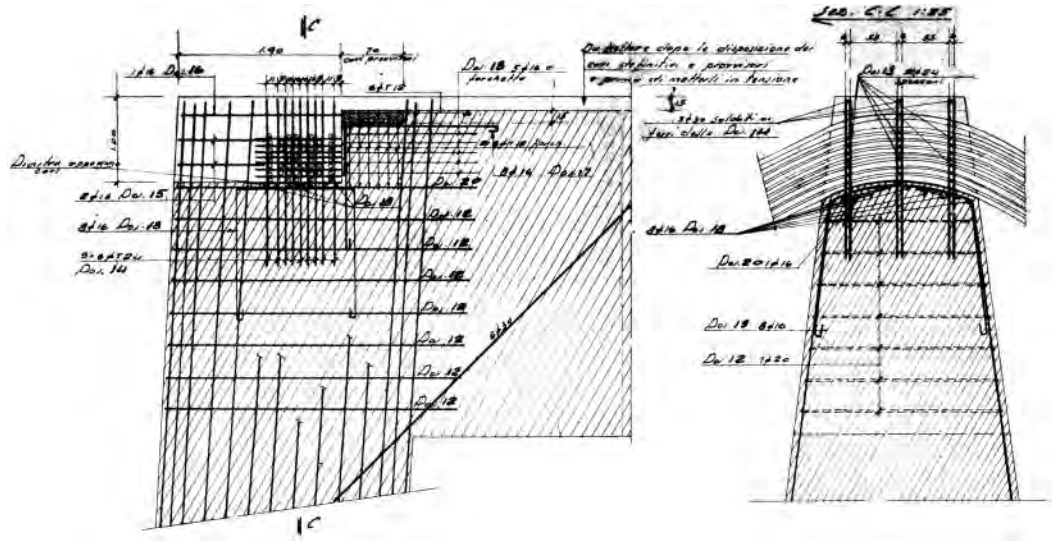

Figure 2. The bridge on the Polcevera River in Genoa. Drawing 299, executive design of pile 9 and pile 10, detail of the saddle, 19 February 1963 (SIXXIdata: Historical archives of the Autostrade Company).

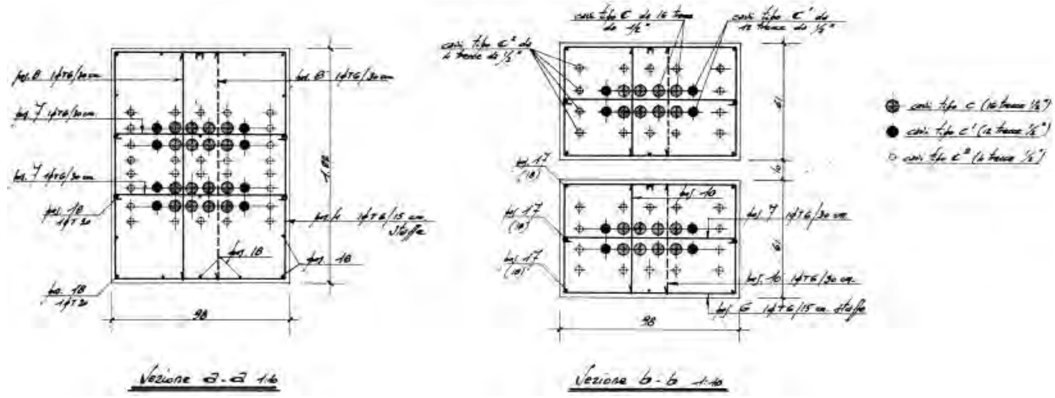

Figure 3. The bridge on the Polcevera River in Genoa. Drawing 327, executive design of pile 9 and pile 10, detail of the stay, 19 February 1963 (SIXXIdata: Central State Archive, Riccardo Morandi Collection).

Nervi understood its real potential, but sometimes before they could be applied, in the hope of finding application (Iori & Poretti 2010). Similarly, Morandi's patents ("M2" in 1949, "M3" in 1952, "M4" in 1955, "M5" in 1961) were not real new inventions: the text of the four patents is practically always the same while the diameter of the cable to be stressed increases from time to time (5 mm, 7 mm, half an inch). It is probable that the trick of re-submitting a new patent served to keep the claims and to prolong the request for royalties to those who used it (including the Condotte Company that built the bridge over the Polcevera) (Iori 2020b) (Figure 4).

For the engineering historian, however, the patent is a "solid" document. But it is essential to know all its limits and peculiarities.

Other documents that crowd this research are the official, possibly registered documents. In order to find a contract or a final static test, we historians are willing to crouch uncomfortably, in a semi-abandoned and dark archive, next to a dead mouse. For some particularly controversial works, even qualified technicians often said that the test certificate was never drawn up: as if this were possible for a public work.

The "Report, visit minutes and test certificate" for the construction works on the 24th lot of the Genoa-Savona motorway – 2.5 kilometres including the bridge over the Polcevera River – consists of 122 pages. They have been signed by the head of the construction company, Condotte, the director of works on behalf of Anas, Luigi Gambardella, and the three members of the testing commission, including the

Figure 4. The bridge on the Polcevera River in Genoa. Pile 10 under construction, detail of the tie-rod cables, 10 October 1966 (SIXXIdata: Archives of the Condotte Company).

expert for static aspects, engineer Carlo Greco. In the report everyone signed the statement that, compared to the contract signed in September 1961 (when, on the other hand, no one knew how to build the balanced cantilevers that overhangs from the pylons), the only project variants were the use of half-inch strands, instead of 7 mm cable, in all pre-stressing operations. With a few sentences, well weighed, the committee is relieved of all responsibility for the executive changes made on site with respect to the 20 preliminary drawings attached to the contract. There were more than 400 executive drawings of the viaduct in the end: a commission's feedback of a few more changes would have been more credible. Also in this case, the certificate had another function, basically an institutional function: it certainly is not used to explain to the historian what really happened during the construction (Iori 2020b).

As another example, during the SIXXI research, the story of the construction of the Risorgimento Bridge over the Tiber in Rome (1909–11) was carefully documented. It is now certain that the drawings attached to the contract had already been completely surpassed at the time of signature. The designer, Hennebique, and the construction company, Porcheddu, were already working on the new project, which was completely different, but could no longer delay the start of the work. Porcheddu had it written in the contract that he could bring variations to the project if these variations were for the benefit of static safety. Is the document with its outdated designs therefore a fake? Of course not: the variant in progress is a constant presence in our SIXXIdata archive. But whoever finds only those official drawings (and not those elaborated for the construction site, never validated by any formal act) could completely misunderstand the functioning of the real bridge (Iori & Savone 2015).

Finally, also in our sources, as in all the respectable historiographies, there are really false documents – not at the level of the "Donation of Constantine", but enough to condition successive episodes of the real history.

In the history of the construction of the Risorgimento Bridge, fake news left tangible consequences: the legend of the early loosening of the scaffolding. Let's remember it: Hennebique wrote to Giovanni Antonio Porcheddu asking that, once they had reached an advanced stage in the casting of the concrete of the bridge's longitudinal walls, in advance of the curing of the material, at night a trained team of workers should go and remove the wedges of the centring, one at a time, according to a precise sequence, and then reposition them but without forcing them. The bridge would be lowered a little, triggering a beneficial process, later called "a plastic adaptation in the most stressed sections". The secret operation was not carried out because a ferryboat crashed into the poles of the centring, broke one and no one had the courage to further disturb the temporary structure. But in 1942, the bridge's calculator, engineer Emilio Giay, told the newspapers that the loosening was done; in the meantime, both Hennebique and Porcheddu had died and could not deny it. Why did Giay do it? Why did Giay tell an "unpublished news" but false, thirty years after a letter he could not show? Perhaps because debate on the bridge had rekindled and doubts about its stability remained, many cracks had been photographed underneath it, and Giay wanted to defend the bridge from the risk of improper interventions, perhaps even demolition, revealing a "magic" procedure that justified the anomalous behaviour of the structure and its "indifference" to the elastic theory. And perhaps also because he wanted to be counted among the protagonists of that "magic"... (Figure 5).

The story of that nocturnal adventure, perpetuated for generations, became "one of the most vivid memories in the career of every engineering student" and certainly consolidated the scepticism of Italian designers towards analytical calculations and their preference for tests on scale models for decades (Iori & Savone 2015).

4 DESIGN VS CONSTRUCTION

There is another classic problem we are dealing with in our historical research: sources can be filtered. It's not necessarily that what we don't find in an archive what has never been there: maybe it simply disappeared. (It happened in recent years that agreements were signed with construction companies to catalogue their archives: in the agreements, the material that could be

Figure 5. The bridge on the Polcevera River in Genoa. Pile 11 under construction, the saddle in the foreground, 12 May 1964 (SIXXIdata: Archives of the Condotte Company).

consulted had to stop at 1992, the year of Tangentopoli, the investigation that unveiled bribes on public works contracts and overwhelmed Italian political life; if we had ever found any later document, we could neither read it nor reproduce it…).

This problem mainly concerns the queen of sources, the one that illuminates our eyes at the moment of discovery but that we had to learn to calibrate: the photos of the construction site. It seems a contradiction: the photos – or the video of the construction site if you are very lucky – would seem the most incontrovertible testimony of the way the work was built. And instead, even the richest collection can hide rather than show.

The scans of about 500 photographs of the construction site of the Polcevera Bridge are collected in the SIXXIdata: over 250 photographs come from the Condotte Company's archive. These photographs show the temporary tie rods and the thousands of work equipments from all perspectives – from the "harp" for the temporary deck prestressing to the cast-in-place form traveller – completely absent from the drawings. However, the photographs only document in detail the building of pile 11, the one closest to Genoa. During the research and before the collapse, it did not seem strange to us: pile 11 was the first to be built, there were probably more doubts to share and document. The pile was also easier to reach than the others, for the photographers charged by the construction company, without struggling to climb the scaffolding. The photos of the other piles are all from afar, panoramic, especially those of pile 9, the last one to be built, far from the Savona and Genoa sides.

And yet, in 2018, the day after the collapse, the American newspapers published a series of photos selected from their expensive databases, dated August 1967, taken by Mario De Biasi, the photojournalist, a paparazzo author of the famous shot, "*Gli italiani si voltano*" (Italians turn around). De Biasi had been commissioned by the magazine, *Epoca*, to produce a report for the August 13th issue (Red 1967). Early in the morning he arrived at the construction site, reached pile 9, climbed dangerously up the stays and reached the top of the antenna, maybe authorised or helped by who knows whom. From up there, he took some unprecedented images that documented the construction site a month before the inauguration. Five photos were then published in the weekly magazine. But not the one that, from the level of the deck, depicts a handsome worker, posing, working on one of the stays of pile 9, sea-side, on the Genoa side, the one that broke first in 2018. In the foreground, in the photo, we see a sheet metal casing wrapping all the half-inch strands. On the contrary, the executive drawings require the cables to be sheathed one by one. No document talks about this casing, no update of the drawings refers to this detail, no calculation considers this modification in progress.

Figure 6. The bridge on the Polcevera River in construction, the stay of pile 9. Photo Mario De Biasi, August 1967 (SIXXIdata).

And above all, why was this variant preferred? What made this simplification necessary? What made it necessary to overcome the sheathing of the cables one by one, as Morandi prescribed? (Figure 6)

The photos in our SIXXIdata database jump from July 7th directly to Giuseppe Saragat's inauguration on September 4th as if there was nothing to document in those two months of final acceleration of the construction site. Instead, the "missing" photos from the archives would be the most precious today. Not even the originals of the photos of the load tests IV, V and VI, which took place on 8 August 1967 on the balanced system supported by pile 10, the largest of the three, can be found today (photos published in the local newspapers). Even "the daily report", which the site manager, engineer Luigi De Sanctis Linotte, will certainly have filled day by day, especially at the end of July, is currently unavailable.

This is surprising, in a database in which everything has been saved: even the telegram that Loris Corbi, general manager of Condotte Company, wrote to Anas on 15 July 1967 to announce the "completion of the demanding viaduct on the Polcevera". That morning, in fact, finally, at the end of yet another 6-month extension granted in January, the Gerber beams that complete the entire deck were launched. (Iori 2020b)

5 CONCLUSIONS

In short, "the sources are traces that the past has transmitted to the present and that we, therefore, find in the present. They are not all we would like to know" (Di Carpegna Falconieri 2020). And for the rest?

In the case of the Polcevera Bridge, unfortunately, we have the autopsies of the ruins – the thin sections of the very cold "Exhibit 132" – which allow us to discover today all that has not been documented. However, we would obviously have all preferred that the bridge was still in place, perhaps after careful and timely maintenance that could have extended its life for many decades.

For all other chances, in chapter XIII of *I Promessi Sposi* (*The Betrothed*), Alessandro Manzoni explained: "*Del resto, quel che facesse precisamente non si può sapere, giacché era solo; e la storia è costretta a indovinare. Fortuna che c'è avvezza*" ("What exactly he was doing we can't know, because he was alone... History is doomed to guess. Luckily enough, it is used to that").

DEDICATION

To the victims of the collapse of the bridge over the Polcevera River.

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Open session: The discipline of Construction History

History of Construction Cultures – Mascarenhas-Mateus & Paula Pires (eds)

Viollet-le-Duc and the *élasticité* of Gothic structures

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ABSTRACT: Gothic architecture, while it looks frail and unstable, has survived for centuries. Some 17th- and 18th-century architects and engineers praised its robustness, but gave no explanation for it. Only Viollet-le-Duc tried to resolve this contradiction. For decades he inspected, surveyed and studied countless Gothic buildings and observed that the stone skeleton, this *charpente de pierre*, was capable of suffering deformations and maintaining equilibrium without collapsing. Viollet-le-Duc called this property *élasticité*: Gothic construction in stone was "elastic", flexible. Viollet-le-Duc's theory was accepted by the next two generations. By the 1920s, several authors strongly criticized its vagueness and contradictions. But it turns out that Viollet-le-Duc's intuition was right. The limit analysis of masonry, developed by Professor Heyman in the 1960s, explains the robustness of the Gothic structure, which can crack and deform safely, finding always a state of stable, safe equilibrium.

1 INTRODUCTION

Gothic architecture looks weak and fragile, a stone skeleton that appears to be in unstable equilibrium, standing almost by miracle. However, the survival for centuries of Gothic structure is unquestionable proof of its robustness. Discussion of Gothic structure has focused on the cross-vault and the function of the ribs, which concentrated the thrust on head of the flying buttresses, and in turn transmitted it to the external buttresses. Various authors have considered the rationality of the Gothic structure, and this discussion prior to the 1960s is best explained in Part IV, "The Scientific Trend" of Frankl (1960: 489–596). However, the problem of Gothic structure's essential safety, its capacity to survive numerous accidents throughout history (winds and storms, wars, soil settlements, abandonment, and so on) has been rarely discussed. Eventually, Heyman (1966) gave the definitive mechanical explanation within the frame of modern limit analysis.

Nevertheless, the debate on the Gothic structure has continued, and the general belief is that there is a unique actual response of the structure to the loads, which can be obtained using a computer program to obtain the "real" state of internal forces in the structure. This fanciful idea is in plain contradiction with the fact that Gothic structure (in fact, any historic structure) has had to adapt itself to countless different loads and to unpredictable small variations of the boundary conditions (for example, settlement of the foundations). The structure moves and cracks, and these movements and cracking can be appreciated by the naked eye in many Gothic churches; yet, the movements are innocuous and somehow the structure can support them.

In the present paper we aim to trace the origins of this idea, which is basic in Gothic design: the conviction that the structure has the capacity to adapt to the different changes of its loads and environment. This conviction must have been more than a mere act of faith on the part of the Gothic master builders, who elevated high vaults on slender supports. What would happen after the decentering and the subsequent thrust of the vaults? What if the high buttresses leaned just a little and the span, at the springing of the vaults, increased, say, by 20 or 30 cm? Is it possible to build a massive tower over the crossing, with pillars designed to support only a light cross vault? Would some sinking of the foundations not occur, with the attendant dislocation and cracking of the masonry? All these phenomena would occur, and the Gothic masters knew that the structure would support them safely.

2 APPRECIATION OF GOTHIC STRUCTURE, 17TH-18TH CENTURIES

Even during the time when it was despised as misshapen and "barbaric", perhaps from the Renaissance until the end of the 18th century, some architects and engineers praised Gothic structure for its lightness and firmness. And as far back as the 17th century, various architects and mathematicians wondered about the miracle of Gothic equilibrium. Guarino Guarini (1624–1683) the great Baroque architect, admired Gothic structures (indeed, he systematically employed Gothic ribs in his vaults). Guarini said that the Gothic "intended to build sturdily, but in such a way that it would appear very fragile, almost as though a miracle was needed for the building to stand up at all … and even if [the buildings] are not pleasant to behold, they astonish the intellect and leave the spectator dumbfounded" (Gargus 1989: 122).

At about the same time, Claude-François Millet Dechales (1621–1678), at the beginning of his treatise

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of stereotomy published in 1674 within his *Cursus seu mundus mathematicus* stated: “This treatise contains the most subtle and exquisite part of Architecture (…) the formation of every sort of Arches and vaults, cutting their stones, and adjusting them which such artifice, that the same gravity and weight which should have precipitated them to the earth, maintain them constantly in the air, supporting one another in virtue of the mutual complication which links them, and in such a way close above masonry buildings with all safety and strength” (Dechales 1690: 619). Here, maybe for the first time, there is an explicit statement on the equilibrium of the masonry structure.

Christopher Wren (1632–1723) did not like the Gothic style, but he appreciated and understood its structural behaviour. He wrote several detailed reports on the safety of Gothic structures. Soo (2007: 34–78) has transcribed and studied those related to St Paul’s Cathedral (before and after the fire), Salisbury Cathedral and Westminster Abbey. Expertise is the main source for assessing structural ideas: the expert is not writing a scholarly text but deciding on the safety of the structure, the measures to be taken. I have found these statements in a series of letters Wren addressed to David Gregory in 1700 on the state of the vaults of the Divinity School in Oxford, which had apparently cracked due to the load of the stalls of the library of the upper floor (Wren 1806). The vaults presented visible cracks due to the leaning of the buttresses. Wren gave no importance to the cracks. In the *Oxonian* the opinion of Wren is summarized: “He has no suspicion of the ruin of that fabrick, and he thinks that notwithstanding all that I told him, of the walls giving from the stalls of the library; the crack in the roof [vault] of the Divinity School from one end to the other; some of the mouldings in that roof falling; and the plains of the buttresses on the south side leaning over in an angle of near one degree, or about two inches in ten feet, by following the directions hereafter set down, it may continue beautiful as well as firm for many years”. In the subsequent letters Wren asked for more information, drawings etc., and eventually arrived to the conclusion that “The fault is in the swelling out of the wall in the library” due to the action of the floor on the vault. In the following discussion Wren crucially states: “I take this for a principle that what is once in aequilibrio doth allwaies rest soe unless the perishing of the materiall induce a new motion or violence from without”, attributing the movement to the action of the truss. However, at the end of the letter, he says: “I confesse I thought soe 30 yeares agoe; but I may be of another opinion, and therefore I desire a trew section”. Having received it, in a later letter, Wren concludes “I am confirmed that the buttresses are not sufficient to poyse so heavy and flat a vault”. He recommends that the cracks merely be filled since they are innocuous, but also that the buttresses on one side be reinforced (and he discusses several options for this action in detail).

I have quoted this report at length because it contains, implicitly, several crucial statements: 1) cracks and leanings are not in themselves dangerous; 2) a structure in equilibrium will remain so unless some external aggression occurs; 3) safety is a matter of geometry, on the proportions of the vault and buttresses. Of course, the particulars of the case should be taken into account – in this case, the buttresses yielded on one of the sides only. Wren is simply expressing, with scholarly clarity, the normal thinking of an experienced master builder (say, a Gothic one).

Wren also observed during the building of St Paul’s over the course of several decades that the huge mass of masonry produced settlements of the foundations. Cracks and leanings appeared and corrections were introduced during the process of construction. These corrections were discovered in the detailed surveys performed around 1900 by the Royal Institute of British Architects (Stancliffe 2004). The same kind of gradual correction was found by Heyman (2018) in the process of building King’s College Chapel.

In France, the engineer Amédée-François Frézier (1682–1773) discussed also the Gothic structure in his treatise of stereotomy. After explaining the advantages of the Gothic cross vaults, praising their lightness and economy, he concludes: “The architects of those times executed good and great constructions with much less expense than we do today, just because of the disposition of the arches of their vaults, but these were deformed” (Frézier 1738: 103). And it was not only engineers who were amazed by Gothic structures. Around two decades later, Anne Robert Jacques Turgot (1727–1781), a French statesman and economist, discussed “the mutual independence of taste and the mechanic procedures in the arts”. Turgot (1808: 325) disliked Gothic architecture but admired its audacity: “There are no edifices of worse taste than the Gothic buildings but, nevertheless, there are no bolder ones, nor ones which demand more activity and cleverness (*lumières*) of practice in the means of execution, though these means could not be other than a succession of a multitude of trials, because the mathematical sciences were [still] in their childhood and the thrusts of the vaults and the roofs could not be calculated with precision” (quoted by Frankl 1960: 394).

Jean-Rodolphe Perronet (1708–1794), the great French bridge builder, also admired Gothic structure in a letter dated 26 January 1770, addressed to Soufflot, who had asked for his opinion on his project for the dome of Sainte Geneviève. In this letter, he detailed the reasons for his admiration for Gothic buildings and noted that “some [Gothic buildings] are surprised to have survived for five or six centuries”. Perronet says that they have been built by imitation of nature and criticized those architects who, because they do not know enough the laws of equilibrium and the art of construction, think that safety increases by unnecessarily increasing the volume of the materials. Finally, Perronet points out that the above considerations and reasoning were which led him to design bold and light vaults, which were of a more solid construction than other more massive bridges: “It is only after similar reflections that I dared to build bolder vaults with much less material that had been made before, and if they did not obtain the approval of those who, when compared to other more massive bridges, believed them less durable, I have not the slightest concern about their safety."

For the present discussion, it should be noted that Perronet also did not care about the cracks and movements of the arches of his bridges. Instead, he observed and registered these phenomena. Perronet was well aware that these surbased arches would settle and deform, that cracks would open and close, and tried to predict and reduce these effects during construction through an adequate counterbalancing of the weights and increasing the height of the arch slightly to avoid a disagreeable "kink" at the crown. This practice later became routine among Perronet and his disciples during the building of these audacious surbased arches. The observations were complemented with tests on models (Huerta 2015).

In England, we can quote James Essex (1722–1784), an English carpenter and architect who, in the introduction of his unpublished treatise on Gothic architecture begun in 1769 and never finished (Jerrold 1977: 62), wondered "(…) by what Principles of Architecture these masses are supported and by what contrivance they are made strong while they appear so light and airey". However, this "is not easily conceived nor can be well understood but by an exact survey of the several parts and a critical examination of their mechanical construction".

3 VIOLLET-LE-DUC AND THE "ELASTICITY" OF MASONRY

We have reviewed some ideas on Gothic structure held by experienced architects and engineers over the centuries, in which Gothic was considered a deformed architecture yet its structure was appreciated for its apparently delicate equilibrium and its economy. Architects and engineers had observed movements and cracks in masonry without great concern, except when there was evidence of continuous deformations. This confidence was based on the tradition of masonry construction: it was an empirical knowledge, absolutely scientific, based on centuries of experience. Each standing building was a successful experiment. But what is the reason for the survival of Gothic structures, which appear so fragile and delicate, over the centuries? How is it possible for Gothic structure to have maintained an equilibrium in spite of (sometimes) frighteningly evident cracks and distortion?

Only Eugène-Emmanuel Viollet-le-Duc (1814–1879) tried to answer these questions. In 1840 when he was an inexperienced 26-year-old architect the beginning of his career, he was commissioned with the restoration of the Basilica of Vézelay (Bercé 2013, 36). The building was abandoned and showed visible cracks and gross deformations: it was a in a ruinous state (Figure 1). Over a period of five years, 1840–1845, Viollet-le-Duc inspected the masonry, redacted a plan of intervention and shored up vaults and walls. Then, he dismounted and rebuilt some vaults, replaced the old (later addition) flying buttresses with new ones, and took all the measures necessary to save the construction.

The task was not free from accidents: one of the vaults – which were not shored up – collapsed suddenly, fortunately without loss of life. Viollet-le-Duc had to tackle head on the question of the safety of a real structure on the verge of collapse. In his intervention, he followed traditional methods, helped no doubt by competent masons (though he complained about them sometimes). But Viollet-le-Duc was not satisfied only with saving the building: he felt an urgent necessity to understand and to explain. His work in Vézelay shaped a large part of his ideas, though we are only concerned here with his explanation of the robustness of the Gothic structure.

There is no space here to dwell on the details of his intervention. All the texts related to it – reports, letters, etc., – have been recently published by Timbert (2013) and his drawings can be seen in the image library of the Réunion des Musées Nationaux – Grand Palais (Rmn-GP). But browsing the documentation on Vézelay, one is impressed by his zeal and intelligence: it appears that not a single detail escaped his attention. Viollet-le-Duc sketched his famous great watercolours showing the state of the masonry, measured and drew the grossly distorted transverse arches. He also designed the shoring of arches, vaults and flying buttresses and, perhaps for the first time, he drew the cracks on the groined and cross vaults – what we now call Sabouret's cracks after Heyman (1983).

It is the detail on the "damages", cracks and leanings, which is pertinent now. We find no attempt at an explanation; most likely he had no time for that. He also needed time to assimilate the formidable amount of information he has amassed. After four years, when he was finishing his intervention in Vézelay, he began to publish a series of papers in the *Annales archéologiques* on the construction of religious buildings in the Middle Ages in France (Viollet-le-Duc: 1844–1847). There, quoting Frankl (1960: 571), "he expounded all his general principles with regard to Gothic, remaining faithful to them for his lifetime".

He observes in particular the cracking of the transverse arches and related it with the outward movement of the buttress system. The arch was distorted, becoming a surbased arch, an arch in "*anse-de-panier*" a basket arch. He realized that this form, observed in many Romanesque barrel vaults was not the original and was produced by the separation of the abutments: "Jusqu'à présent toutes les observations que nous avons pu faire sur les voûtes dites en anse de panier, nous ont laissé la certitude (dans celles que nous avons vues du moins) que cette forme n'est causée que par un accident, l'écartement des murs" (Viollet-le-Duc 1844: 184). Later on in the same paper he calls a construction which can experiment these changes "élastique": "Le XI^{e} siècle commence à pratiquer, aussi ce mode

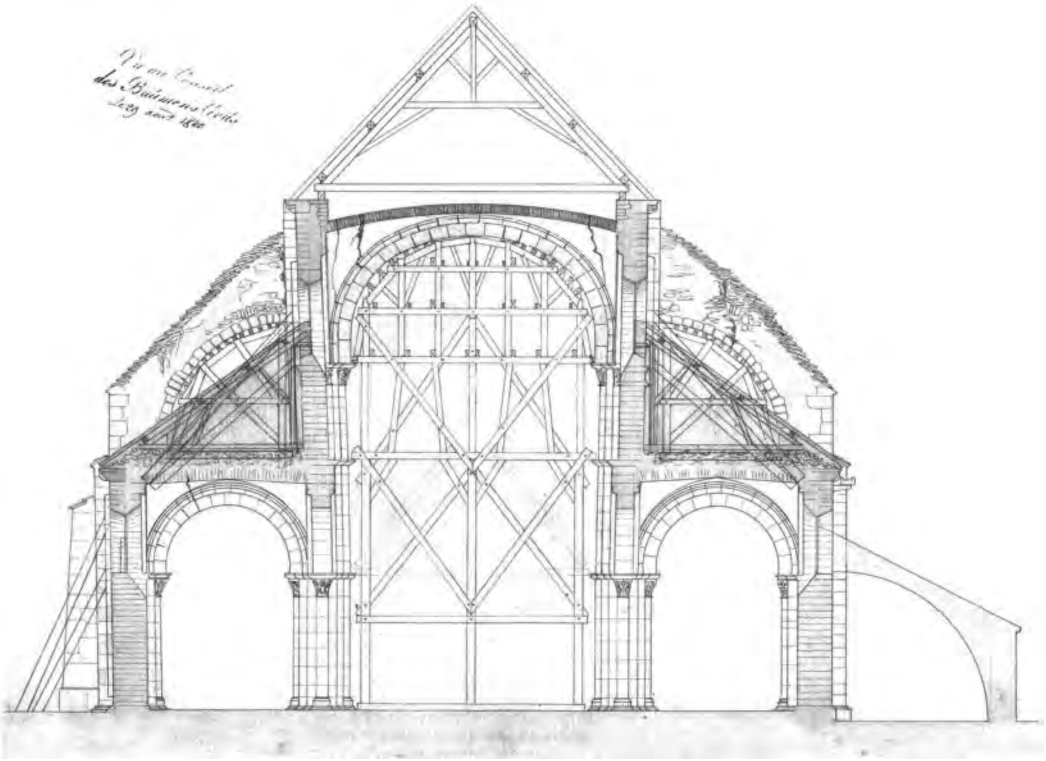

Figure 1. Deformed state of the nave of Vézelay in the 1840s (Viollet-le-Duc, Images d'art. Réunion des Musées Nationaux – Grand Palais. Detail).

de construction élastique, entrevu par les Romains, si nécessaire dans les grands édifices, et que le XIII^{e} siècle a perfectionné d'une manière si extraordinaire" (my emphasis). This kind of "elastic construction" was foreseen by the Romans, and Viollet-le-Duc refers to the well-dressed ashlar external walls in some Roman constructions. Ashlar masonry could crack and adapt and is therefore "elastic". He uses this idea to differentiate Gothic from Romanesque construction: Gothic construction is elastic – as opposed to Romanesque, which, like Roman construction, is monolithic and in danger of collapse at the slightest settlement of the foundations: "cette construction toute d'une pièce (…) Le moindre tassement, le moindre mouvement dans: la construction brisaient ces voûtes cassantes; et, une fois lézardées, elles devaient s'écrouler".

He then argues that the architects of the 12th century understood this danger; they realized that mounting their vaults on top of a skeleton of elastic arches such as transverse arches made it possible for the whole vault to move and the inevitable settlements would be innocuous: "Les architectes du XII^{e} siècle comprirent ces dangers. Ils sentirent bien que s'ils pouvaient donner à ces voûtes l'élasticité qu'avaient leurs arcs doubleaux, ils n'auraient plus aucun mauvais effet à craindre des tassements inévitables dans des constructions d'une grande étendue" (Viollet-le-Duc 1844: 143). The ribs, made of well-cut voussoirs, must be independent from the webs made of rubble masonry, "moellons". To construct the vault only the centering for the cross and transverse arches is needed; they constitute a stone centring, and the cross-ribs are "cintres de pierre … qui, portant les quatre triangles de la voûte d'arête, les rendirent indépendants les uns des autres." A flexible, elastic, stone skeleton supports the independent compartments of the vault, which, in turn, becomes also elastic, flexible, and adaptable. However, the pillars which support the vaults – because "Toute la puissance de ces constructions consiste dans les points d'appui" ("all the force of these constructions lies in the support points") – should be able to move and adapt, "car il faut qu'elles suivent les mouvements, soit d'écartement, soit de retrait, qui peuvent se faire dans la construction" ("since this means they can follow any movements, whether spacing or yielding, that might occur in the construction") (Viollet-le-Duc 1846: 272).

The picture is now complete: the whole Gothic structure can move and adapt: it is "elastic". But there are evident contradictions. What happens with the hundreds of Romanesque churches with barrel and groin vaults which were standing before Viollet-le-Duc eyes, grossly distorted, but undoubtedly safe, as their mere survival showed? The "accidents", the soil settlements which caused the yielding and spacing of the pillars and abutments, not only occurred in the 12th and

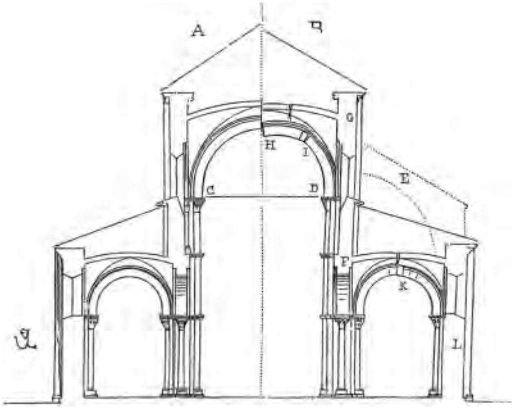

Figure 2. Movement due to yielding of the abutment wall (Viollet-le-Duc 1854: IV, 26).

13th centuries. In fact, any masonry structure since the beginning of civilization had had to cope with the same.

One cannot build a new theory without some form of limitations; the researcher has to concentrate on a small range of problems, make certain assumptions. Only afterwards it is possible to check the theory with reference to more general phenomena. Viollet-le-Duc concentrated on explaining the robustness, the capacity to adapt, of delicate Gothic structures. The long previous quotations, the evident contradictions, are intended to show the formidable effort required to think something anew, to build this new theory.

In 1854, some 14 years after his first visit to Vézelay, when he published his *Dictionnaire,* everything was clear to Viollet-le-Duc. By then he has accumulated an enormous knowledge, practical and theoretical, on Gothic construction. The countless visits to inspect churches, the restoration works, the careful measurements and analytical drawings, confirmed his intuitions. The elasticity of the Gothic construction had become a "principe", a principle, which guaranteed its safety: "ce principe d'élasticité appliqué à ces grandes bâtisses et sans lequel leur stabilité serait compromise" (Viollet-le-Duc 1854: I, 64). Thanks to their elasticity, these buildings had stood for six centuries in spite of frightening deformations: "malgré des déformations effrayantes subies par quelques-uns de ces monuments, ils n'en sont pas moins restés debout depuis six cents ans, grâce à l'élasticité de ce mode de construction" (Viollet-le-Duc 1854: I, 66).

The arches, elastic and deformable – like any arch made up of a certain quantity of voussoirs – acted as permanent centrings and could follow the movements of the piers or the yielding of the buttresses, always supporting the vault webs: "Ces arcs doubleaux, sortes de cintres permanents élastiques, comme tout arc composé d'une certaine quantité de claveaux, suivaient les mouvements des piles, se prêtaient à leur tassement, à leur écartément, et maintenaient ainsi, comme l'aurait fait un cintre en bois, les concavités en maçonneries bâties au-dessus d'eux" (Viollet-le-Duc 1854: IV, 14).

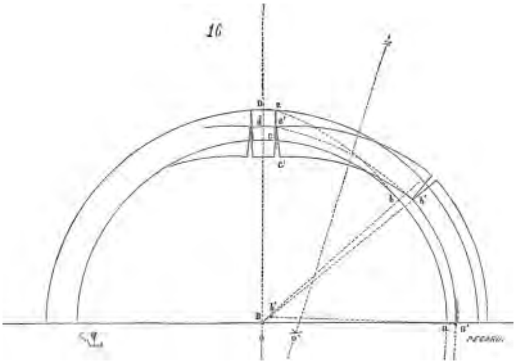

Figure 3. Cracking and geometry of deformation of a voussoir arch (Viollet-le-Duc 1854, IV, 27).

And now, Viollet-le-Duc finally explains the deformability of the masonry arch, with reference to the transverse arches of Vézelay, which he surveyed so carefully 14 years before. Figure 2 shows, on the left the undeformed section; on the right, the distorted form after the yielding outwards of the upper part of the wall FG. The crown H descends and a "hinge" forms in I. Though Viollet-le-Duc draws a true hinge, the borders of two adjacent voussoirs touching and rotating around the contact, he describes this as "l'écrasement des claveaux des reins", the crushing of the voussoirs of the reins. (The formation of hinging cracks during the collapse of arches was well known to the French engineers of the first half of the 19th century; the joint in I was called "joint de rupture", the breaking joint. Viollet-le-Duc seems to be unaware of this. However, it should be noted that engineers were not concerned with explaining the movements of arches, but on obtaining the value of thrust in a collapse mechanism.)

Then, Viollet-le-Duc offers the first detailed drawing of the geometry of deformation of an arch due to the spreading of its abutments (Figure 3). Placing the joint de rupture a little below 45°, he computed the descent of the keystone Dd due to an increase of the span GG'. If the increase is of 20 cm on each side, the keystone will descend 40 cm. The deformed arch has been converted into a basket arch. The dimensions used by Viollet-le-Duc are those of the transverse arch in Vézelay, and comparing with his drawing of "état actuel", the current state, made in 1840 (Figure 1). The magnitude of the descent coincides, though in the old drawing no clear "kink" or discontinuity of curvature is shown. However, Viollet-le-Duc uses the geometry of deformation not to justify the "elasticity" of the arch, but to explain the origin and advantages of the pointed arch, which is not pertinent now.

Throughout the *Dictionnaire,* Viollet repeats and reformulates his principle of elasticity. Crucially, he combines it with another principle of "équilibre", equilibrium. Of course, it is evident that if a structure stands is in equilibrium, but none before him expresses the idea of the structure moving and deforming, looking for new states of equilibrium. Viollet-le-Duc is not referring, of course, to unstable equilibrium, but of safe, stable equilibrium.

The construction is supported by a structure, a "charpente de pierre" (stone truss). This skeleton can be rigid or flexible, depending on the need and the place: it yields or resists; it seems to be alive, for it obeys contrary forces; and its immobility is obtained by means of the equilibrium of these forces: "Ce squelette est rigide ou flexible, suivant le besoin et la place; il cède ou résiste; il semble posséder une vie, car il obéit à des forces contraires, et son immobilité n'est obtenue qu'au moyen de l'équilibre de ces forces (…)" (Viollet-le-Duc 1854: IV, 127). This sentence summarizes his theory in a vivid, categorical, almost poetic way.

There is more material worth quoting. For example, when discussing the term "*étai*" (shoring) Viollet remarks, again, that elastic and flexible Gothic buildings are always in equilibrium, and these properties could be very useful in shoring, if you know them exactly – or they can cause accidents if you ignore them: "Les édifices de la période gothique étant élastiques, toujours équilibrés, il arrive que ces propriétés peuvent vous servir si vous les connaissez exactement, ou qu'elles peuvent déterminer des accidents si vous n'en tenez compte" (Viollet-le-Duc 1861: V, 344).

This "elasticity" of Gothic structures was accepted by the next two generations that followed. In particular, it was adopted by Auguste Choisy (1841–1909), an *ingénieur des Ponts et Chaussées*, in his *Histoire de l'architecture* (1899), a book that achieved an extraordinarily wide reach and influence all over Europe. Choisy stressed the adaptation to the inevitable settlements of the foundations in such tall buildings, which developed enormous loads; this adaptation required a somewhat elastic masonry: "(…) il s'agissait … de constructions d'une hauteur jusqu'alors inusitée, où se développaient des charges énormes; il fallait compter avec les affaissements du sol, avec les tassements qui pouvaient survenir dans ces masses: la solidité de l'oeuvre devait être autant que possible indépendante de ces causes de déformation, il fallait des maçonneries pour ainsi dire élastiques" (Choisy 1899, II, 259). With regard to the cross vaults, Choisy stated that they are flexible and deformable, and will follow all the movements produced by the settlements: "la voûte nervée est pour ainsi dire flexible et déformable: les points d'appui peuvent tasser, les piles se déverser, elle en suivra les mouvements" (Choisy 1899: II, 270). With reference to his last sentence, Frankl (1960: 577) remarked: "When an expert like Choisy said that, it is no wonder that whole generations of architects and art scholars calmly continued to live and theorize under Viollet-le-Duc's influence, although they must all have known that Gothic transverse arches, ribs, and vaults were not made of rubber." Frankl was right; maybe it is too good to be true. Gothic vaults are not made of rubber, and masonry is not elastic, but the problem remained of explaining the mere survival of these structures. Critics of Viollet-le-Duc concentrated on the terms employed and ignore the problem investigated. See for example, a frontal attack from Abraham (1934). Nevertheless, Viollet-le-Duc was, at least, empirically right: the Gothic constructions which he had studied with so much zeal throughout his life had had to move and adapt, always in safe equilibrium, over centuries. His principle of the "*élasticité*" of masonry, based on his formidable knowledge of Gothic constructions, may lack scientific rigor – the term is unfortunate, and contains many leaps into the unknown. But at least he did not turn a blind eye to the essential robustness of the Gothic, and addressed the problem in a frank and direct way.

4 CONCLUSION: HEYMAN'S PARADIGM OF EQUILIBRIUM

The solution needed a new theoretical framework. One hundred years later, in 1966, professor Heyman of Cambridge published his seminal article "The Stone Skeleton", which was followed by series of papers and books dedicated to the structural theory of masonry (too numerous to be quoted, see in particular Heyman 1968, 1995, 2008). Heyman showed that masonry architecture, including Gothic, could be analysed within the frame of modern limit analysis of masonry structures. Within this theoretical framework, the safety of a masonry structure depends on its geometry. If the geometry permits the structure a "comfortable" state of internal forces in equilibrium with the loads, then, this structure will never collapse. This equilibrium approach constitutes a "new paradigm" in understanding the mechanics and construction of all historic masonry architecture, including Gothic.

The masonry structure may suffer different "aggressions", for example the settlements alluded by Viollet-le-Duc and Choisy, and it will respond by cracking and moving – "as if it were alive". As long as these distortions are "small" (in relation to the overall dimensions), and that they do not alter the global geometry of the structure, the building will remain in safe equilibrium. The state of internal forces may vary drastically: in a Gothic cross-vault, the loads may be transmitted through the ribs, through the webs, or any combination of the two mechanisms (see Heyman 1995; Huerta 2009). This is both impossible to know, and irrelevant. The geometry of a safe masonry structure permits infinite equilibrium states; the structure itself will look for a comfortable state – and find it!

Medieval master builders were aware of this. They knew that safe equilibrium is obtained by geometrical design. They had gained this knowledge through critical observation of old buildings and buildings under construction. In fact, Viollet-le-Duc apprenticeship was "medieval", and eventually he acquired the same degree of confidence in masonry as the medieval masters. Thanks to the work of Professor Heyman we can shorten our path to an understanding through dedicated study and reflection. But as an anonymous engineer stated in mid-19th century: "Those who would acquire a thorough knowledge of the [masonry] arch, will never get it from books alone (…) We have only shown the alphabet, with the aid of which they may spell out their learning from actual structures and the practical experience that is gained from real work" (Anon. 1861, 349).

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History of Construction Cultures – Mascarenhas-Mateus & Paula Pires (eds)

Finding value in the ordinary to better understand the extraordinary. Systematic surveys in baroque roofs and medieval log-buildings

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ABSTRACT: Using two examples, this paper argues for the benefits in properly examining the supposed 'normal' or 'standard' constructions in order to better understand certain aspects of innovation or even make extraordinary discoveries. The systematic examination of numerous roof trusses over single-nave churches in German-speaking Switzerland in the first example give us a vivid picture of the construction methods in various regions over a span of 250 years. Based on these constructions, one can see which systems or approaches in constructing roofs were carried forward and which were not. In the case of the late-medieval log buildings in central Switzerland it is shown that within a rather run-down residential building lies the potential of great discoveries. Through systematic surveys and with the help of dendrochronology, over 30 log buildings have been discovered and documented dating back as far as 1300.

1 WHAT EXACTLY IS "EXTRAORDINARY"?

The field of construction history, for most part thrives on extraordinary and innovative solutions. But what constitutes the so-called "extraordinary"? What makes it stand out from the "ordinary"? How to define innovation and its influence on the built environment and the subsequent methods of construction? In order to answer these questions satisfactorily, one first needs to know what exactly defines the "normal" or the "ordinary". On one hand, it is by examining objects that have been built multiple times in a similar way, under similar circumstances and under the same technical conditions that one can start to build up an understanding of the standard methods. Similarly, questions about the typical planning of the building, the organization of the construction site and the construction process itself can only be answered satisfactorily if we first know what the "normal" is. On the other hand, it is possible that the supposedly "ordinary" in itself is more complex than assumed and has something extraordinary to offer if one only takes a closer look at it. This paper uses two separate pre-modern examples in timber construction in Switzerland that are based on the author's current and past studies, to show that the scientific examination of the ordinary, even the everyday, certainly has its potential and its merits.

2 "CRITICAL MASS" THROUGH SHEER NUMBERS: ROOFS OVER BAROQUE CATHOLIC SINGLE-NAVE CHURCHES IN GERMAN-SPEAKING SWITZERLAND

Church construction represented a significant part of the building industry in today's Switzerland from the 17th century up to the middle of the 19th century. In both Protestant and Catholic areas of central, northern and eastern Switzerland, one can speak of a veritable building boom, especially in the 18th century. In rural areas, in most cases single-nave churches were erected, showing a nave without intermediate support such as columns or pillars. At the end of the 18th century, these churches were somewhat standardized in their architectural form as well as decor (so-called "Landkirchenschema") and sometimes reached spans of over 20 m. A current project under the direction of professor Stefan Holzer and funded by the Swiss National Science Foundation (SNSF) consists in systematically investigating, for the first time, the roofs over these wide-span buildings in order to trace the developments in building technology and construction from 1600 to the middle of the 19th century. Up to now, research has primarily dealt with the architecture of these rural churches (Grünenfelder 1967; Horat 1980) or focused on a single family of master builders and their roof constructions or wooden bridges (Killer 1942). When studying the Catholic churches, it quickly became clear that the sheer number of single-nave churches built during the investigated period with a span larger than 10 m does not allow a selection of case studies to be made without preliminary visits to all of the roofs. On these occasions, a cross-section of the main roof truss was taken from each of the 101 churches, their construction being described and documented photographically (Figure 1). Since the task of building a roof truss over a single nave is always the same, this inventory of roof trusses provides an ideal basis for comparison. In the study area, especially in the late 18th century, different master builders or entire families of master builders decisively dominated the building trade. For example, Niklaus Purtschert

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(1750–1815) can certainly be considered as architect and planner of eight churches in Central Switzerland. Jakob Singer (1718–1788) is also sure to have built a total of eight single-nave churches. In today's canton of St. Gallen, Johann Ferdinand Beer (1731–1789), who was based in the Vorarlberg, designed and built about the same number of church buildings. Generally, the master builder would be responsible of the entire construction, including the works in stone and wood, and often the decoration in the form of stucco and vault paintings. Depending on region and time, the different tasks were then carried out by the master builder's more or less permanent construction team, which included at least masons and carpenters. In other cases, the master builder assigned the execution of his plans in sub-contracts to specialized craftsmen. The general construction method of the examined church roofs is in any case the so-called "liegender Stuhl", usually combined with a form of king or queen post. When comparing the roofs of the churches of the aforementioned master builders, minor but distinct constructional differences are noticeable. The comparison of several of the roof trusses by the same master builder clearly shows that the same construction variant was always employed. Obviously, each master builder had a kind of standard roof construction. For the master builder Niklaus Purtschert, for example, it is typical that individual trusses with cross braces are distributed at regular intervals over the nave roof (Figure 2). Interestingly, no other master builder of his time used this specific arrangement of roof trusses. On the basis of this observation and by looking at preserved plans, it is therefore evident that the master builder who designed the church (the architect, in modern terms) also designed the roof construction, even though all the above-mentioned master builders

Figure 1. Catholic church St. Jakob in Cham, Canton of Zug, Switzerland. Overview over the roof truss, erected in late Summer or Fall 1784 (Gantner 2018).

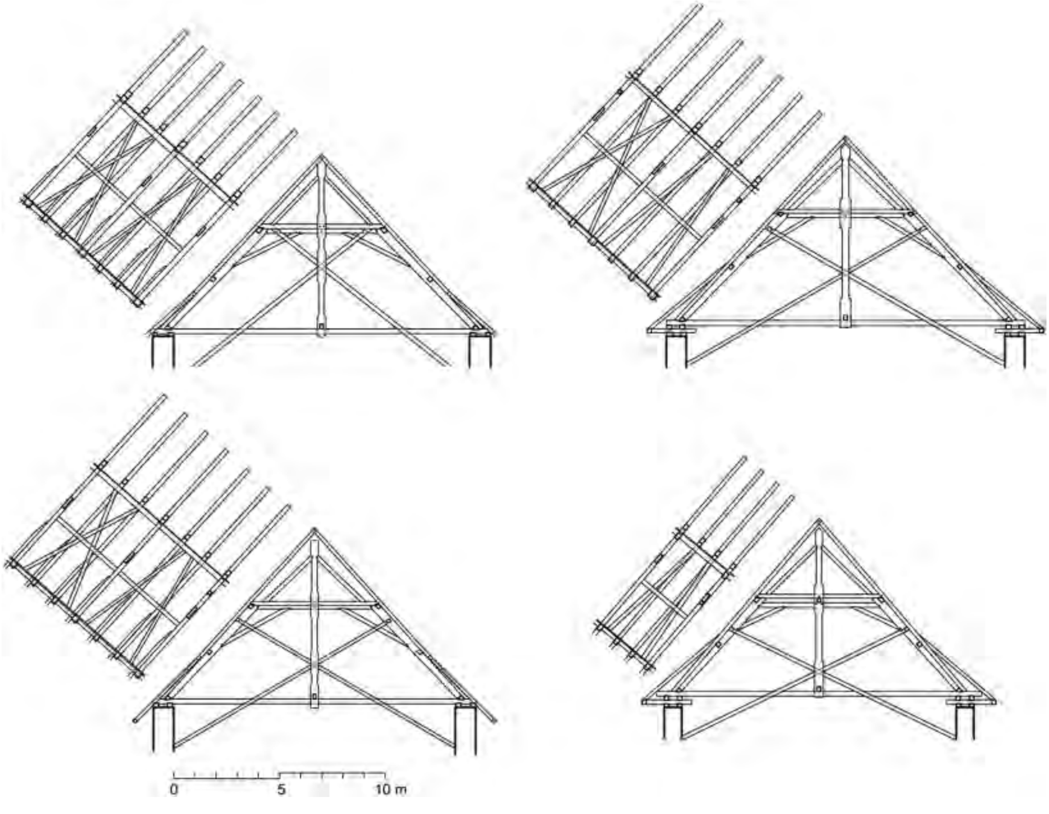

Figure 2. Comparison: roof trusses designed Niklaus Purtschert and built by various sub-contracted carpenters between 1778 and 1802. Cross braces in roofs with continuous tie beams are typical for this particular master builder (M. Gantner, 2019).

Singer, Purtschert, and Beer were trained as stonemasons. The fact that apparently each master builder applied a standard construction can be used to provide an additional level of argumentation in questions of the attribution of individual church buildings (Gantner 2020). In contrast to the visible architecture, which is subject to the taste of the times and to representation, it is only the efficiency of the construction which is important when designing a roof truss. It must be able to span the nave safely and permanently. The design and structural understanding of the roof, depending on the span and the ceiling construction, was certainly based on experience and apparently passed on from masters to students or employees. Thus, we find the same construction principles typical for Purtschert in early 19th century church roofs that were planned and built by master builders who had participated in Niklaus Purtschert's construction team a couple years earlier (Figure 3). The situation is similar with the church buildings of Josef Singer, Jakob Singer's son. Here too, his typical construction elements and their design were carried forward. Those master builders, who in architectural history are referred as "the heirs of Singer and Purtschert" (Reinle 1963, 366), not only took over the architectural scheme of the country church, but also the construction methods and the design of the roof trusses from their teachers. Although written sources and other historical documents vary greatly in terms of quality and quantity from region to region and over time, some statements can be made about the building industry, the organization and the building process of the Catholic rural churches (these also largely apply to Protestant church construction). As already mentioned, most building contracts were awarded as a whole, and the designing master builder was normally also the executing one. In addition, changes of plan during construction, which can be observed in buildings of the highest ranks, are extremely rare. Moreover, the construction time of the buildings can be delimited relatively well in most cases. Already Josef Killer (1942), in his work on the Grubenmann family of master builders in Appenzell, noted that the shell of the church buildings was, as much as possible, completed within one building season (spring to autumn). This procedure can also be traced in the examined Catholic churches. After the first foundation stone was laid ceremoniously in spring, the masonry was completed relatively quickly so that the roof could be erected in late autumn at the latest. The parish church in Cham in the Canton Zug, one of the largest investigated with a span of over 17 m was covered by its roof in 1784, merely seven months after the laying of the first foundation stone in May (Figure 4. Grünenfelder 2006, 75). The vault, typically a wood-lath-plaster construction, as well as the entire interior decoration was only built afterwards. Therefore, dated paintings on the ceiling serve as a *terminus ante quem* for the erection of the roof trusses. On the

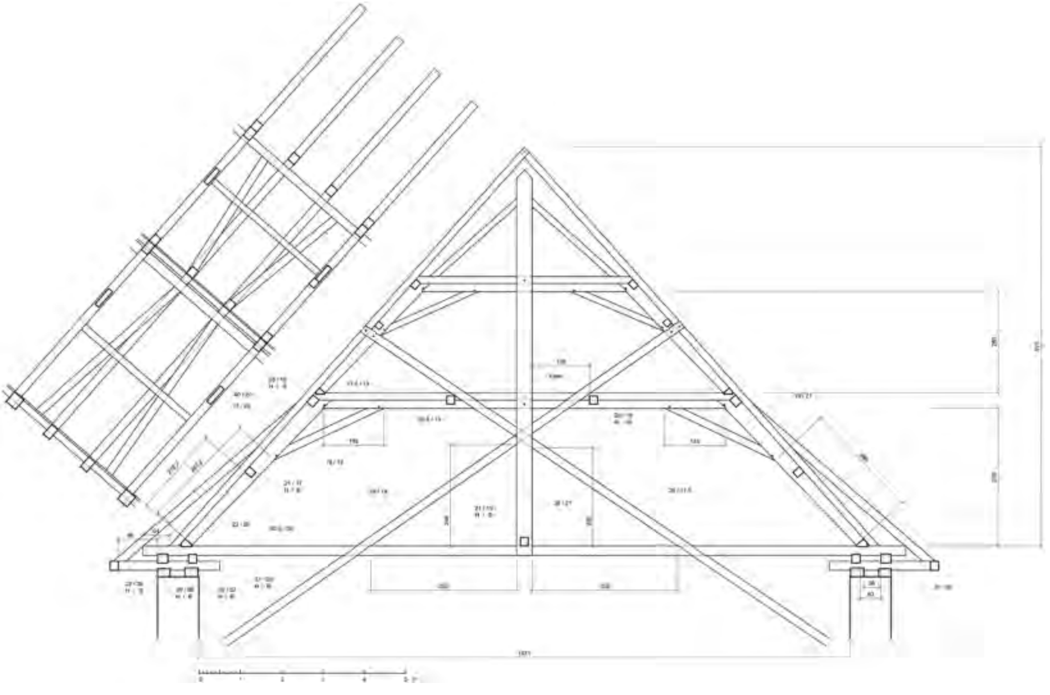

Figure 3. Catholic church St. Laurentius in Dagmersellen, Canton of Lucerne, Switzerland. Cross section of truss No. 3, erected in 1820 or the year prior. The two brothers Josef and Franz Händle, originally based in Tyrol, are known to have worked for Niklaus Purtschert prior to becoming Master builders on their own. Obviously, their roof trusses bear lot of similarities to those designed by their former employer (M. Gantner, 2018).

basis of historical sources, as well as through the dendrochronological evaluation of selected trusses, it is also possible to shed more light on the timber industry and the origin of timber. As far as the constructions are concerned, the large number of objects examined makes it easy to highlight innovations and their possible diffusion. In contrast, one can thus also pinpoint innovative ideas which remained unique and were not established, perhaps because they were considered too elaborate or not practical enough. Through the looking glass of the normal, innovation becomes somewhat more recognizable and classifiable in terms of its impact on later construction methods. In addition, the strengthening strategies for damaged roof structures can be better understood. Indeed, in some 18th century roof structures with interrupted tie beams, the various strengthening measures from the first half of the 19th century are very similarly conceived and give ideas which effects were intended (Gantner 2021).

From a conventional point of view, the individual constructions hold perhaps nothing extraordinary in themselves. Nevertheless, the sum of the built constructions exhibits how rational and in a certain sense economical these master builders already worked more than 200 years ago. The entire building boom of the late 18th century can in this sense be described as quite extraordinary. Through the systematic examination of the roofs of these rural single-nave churches, a high-resolution picture of the “roof landscapes" could be obtained, which on the one hand shows what can be regarded as the standard of construction at a certain time, reveling which construction details were typical for a region or for a school of master builders. On the other hand, it offers an ideal starting point for follow-up projects, which may extend the parameters regionally or time wise.

3 KEEP YOUR EYES PEELED! LATE MEDIEVAL LOG BUILDINGS IN CENTRAL SWITZERLAND

Since the late 19th century, it has been assumed that a particularly old stock of log buildings might have been preserved in certain areas of central Switzerland. With dendrochronology as a dating method used since the 1980s, this assumption could be scientifically proven for the first time by successfully dating the timber used for the construction of the “Haus Bethlehem” in Schwyz to the year 1287 (Descoeudres 2007, 11). This makes the house one of the oldest preserved residential buildings in Europe. Subsequent research led to the identification of certain construction features that are typical of these medieval log buildings (Descoeudres 2007; Furrer 1988). The most apparent of those features are the so-called “Einzelvorstösse”. This means that only single logs of the inner walls really penetrate the outer walls (Figure 5). The remaining log ends are embedded in a dovetail-shaped groove, so that they are not visible on the exterior of the building. Another telltale sign of such a medieval log

Figure 4. Catholic church St. Jakob in Cham, Canton of Zug, Switzerland. Interior view of the nave with the typical late baroque stucco decorations and ceiling paintings by Joseph Keller and Joseph Anton Mesmer, dated 1785 (M. Gantner 2018).

construction are floor and ceiling planks that are visible from the façade ("fassadensichtige Boden- und Decken-bohlen"). From the middle of the 15th century onwards, the floor and ceiling planks are all around notched in the outer walls and therefore not visible from the outside (Gollnick 2018, 149–151). Due to the presence of these distinct features and through targeted surveys on buildings that were to be demolished or converted, as well as with the help of dendrochronology, over 30 of these log buildings from the 14th century have already been identified in the Canton of Schwyz, some of which have been dated to the exact year, documented and scientifically investigated (Brunner 2016, 248–253.). These log buildings from the early period of the Old Swiss Confederation ("Eidgenossenschaft") that have been examined provide insight into the highly developed art of carpentry (Gollnick & Rösch 2018). The notion emerged that – contrary to the long-held interpretation of a wooden building as a farmer's house – these late medieval log buildings were the dwellings of a local, perhaps regional ruling class or at least of socially higher-ranking persons (Descoeudres 2007, 76–77). The buildings are two-story log constructions rising above a masonry stone base (Figure 6). Each of the approximately 100 wooden logs of spruce or fir, which were needed for a single house, is made out of one single tree precisely shaped with a broad axe. The beams were stacked on top of each other on the short edge

Figure 5. So-called "Haus Bethlehem" Schwyz, Canton of Schwyz. The building logs of this House are dated to 1287 by dendrochronology. Note that the windows as well as the arbors are not original to the medieval building (Gantner 2013).

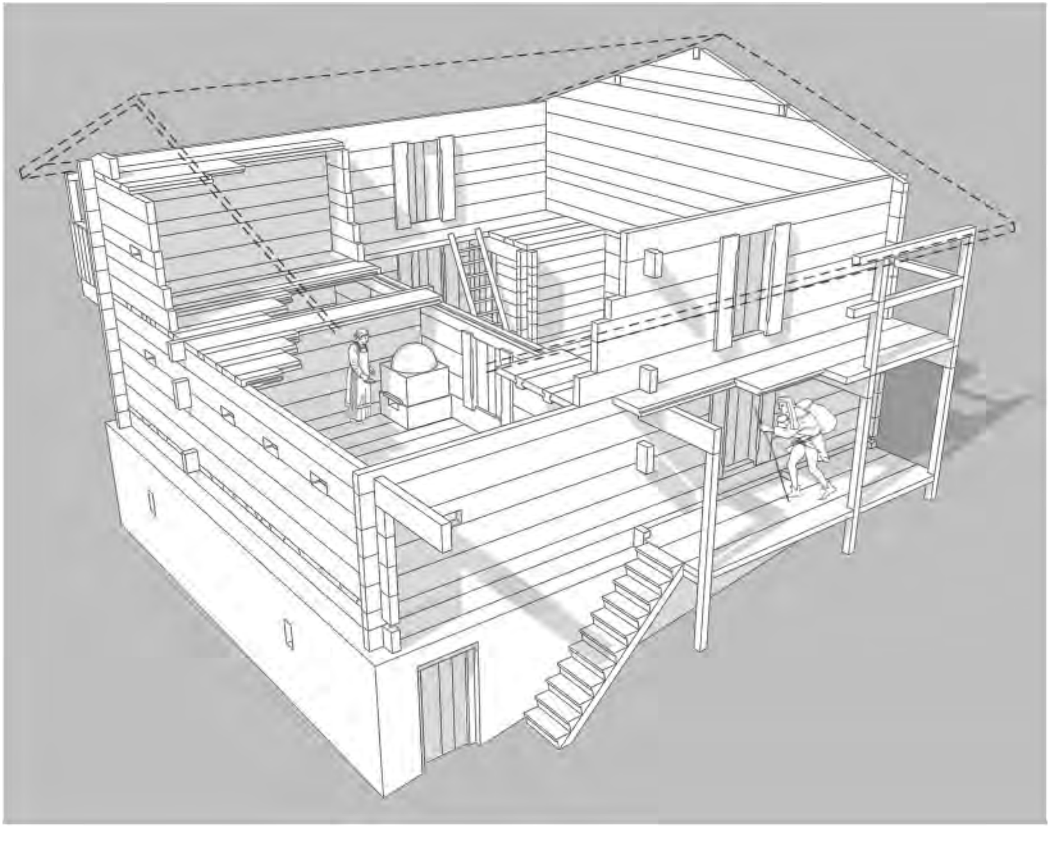

Figure 6. Perspective reconstruction of the house Gütschweg 11 (dated 1311) in Schwyz, Canton Schwyz, Switzerland. Only individual beams of the inner walls penetrate the outer wall of the log construction. In addition, the floor and ceiling planks are visible on the facades (reconstruction by U. Gollnick and P. Frey, 2016).

and additionally secured with vertically inserted dowels. The corners of the house square were interlocked to create the cross shape typical of log construction. The house entrances were located on the eaves side, and the doorways were usually equipped with a post that partially surrounded the ends of the logged wall. As windows in the 14th century, one must imagine hatch-like, long rectangular openings, which could be closed by simple board shutters (Descoeudres 2007, 29–33). The roof was constructed as a simple purlin roof and had a shallow pitch. Interestingly, all the log buildings examined share the same general interior layout (Descoeudres 2007, 40–52): the rooms in the front area of the house are considered as living and working spaces which could be heated smoke-free by means of a tiled stove as early as the 14th century. In the rear part of the house, there was a hallway leading across the house, the open-fire kitchen open up to the roof, as well as small chambers in the rear corners of the house. On the sides of the eaves there were loggias which could be entered from the inside of the house. This basic spatial disposition of a front living part and a rear economic part can be observed in rural wooden dwellings in the typical log construction regions of Switzerland until well into the 20th century.

The preserved log buildings allow us not only to examine their construction and layout, but also the traces left by the inhabitants of these houses over the past 700 years. Thus, a small history of dwelling can be traced, ranging from the black-painted, block-faced parlors of the late Middle Ages (Marinowitz 2016), through the ornate paneling of the 17th and 18th centuries, to the wallpaper of the 19th century and finally to the industrially produced paneling or plaster walls of the 20th century. On the basis of certain findings, it is also possible to draw conclusions about the practice of handicraft. Some traces also allow an insight into the world of faith of the former inhabitants. Prints with Christian content bear witness to the deep religiousness of the people, while objects hidden in dowel holes and jammed into crevices also allow an interpretation of what could be called superstition today (Gollnick 2016).

Many of these buildings, wherein a kernel of a medieval log building is preserved are somewhat rundown residential buildings that have been transformed countless times and where, at first glance, one does not recognize the hidden secrets these dwellings hold (Figure 7). Due to settlement pressure, these very buildings are increasingly threatened by demolition, and many have been demolished after or even during investigation and documentation. In worst-case situations, the demolition occurred even before the documentation of the building. The archaeological approach of prospecting and, if necessary, documenting and investigating those buildings or structures that are in danger of disappearing is one way of preserving exceptional historical constructions for posterity, revealing extraordinary, perhaps even unique constructions to be seen at only the second glance. Ideally, the investigation and public awareness work can make the extraordinary value of the object understandable to the extent that it can be spared from demolition and instead be transformed or converted.

Figure 7. House Gütschweg 11, Schwyz, Canton Schwyz, Switzerland. The building before the investigations. Traced, the late medieval log construction from 1311, which was in large parts intact at the time of the survey (Gollnick & Frey 2016).

4 CONCLUSIONS

There is absolutely nothing wrong with examining the extraordinary buildings of this earth, deciphering their history and documenting their innovative constructions. Nevertheless, as the example with the baroque roofs shows, an understanding is needed of what can be considered standard at a certain time and in a certain region and how the building industry was organized in each instance. This is the most certain way to classify and correctly understand the constructions that are labeled as innovative. Similarly, a closer look at the “normal” shows whether and how new ideas were implemented, which innovations resonated, possibly even became the new standard or which remained unique. The example of the log buildings shows that the extraordinary can be revealed behind the unimposing. In this case, one has to know what to look for. In addition, there must be the possibility to probe the objects, if necessary, meticulously examine them and, whenever possible, preserve them for posterity.

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History of Construction Cultures – Mascarenhas-Mateus & Paula Pires (eds)

The post-war construction site in photographs: The photographic collection of the Belgian contractor firm Van Laere (1938)

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ABSTRACT: Since the 19th century, construction site photographs have been a means of documenting the building process. However, the way in which the photographs are created, how they are viewed and how they are used, creates a context that influences what can be seen in the image. The question of how this evolved after 1945 still remains largely open until today. By means of a case study into the photo archive of the Antwerp firm Van Laere (1938), this article attempts to convey how the context and evolution of the company influenced the creation of their visual archive but also the stories within individual images. The history of the company is interrogated through a series of interviews and analysis of their photographic collection. The paper aims to demonstrate that this context should certainly be taken into account in any further use of photographs as source material.

1 INTRODUCTION

Construction sites are characterized over time by their ephemeral character. They typically only exist for a very short time, and then merge into the built result. The building process that led to this result therefore disappears into the background. Since classical antiquity, attempts have therefore been made to document this process visually. The rise of photography in the second half of the 19th century brought with it a whole range of new possibilities. Because of the revolutionary character of the medium itself, but also because of the enormous building fever that reigned at the time in Western Europe, the building process attracted the attention of both professional and amateur photographers. In this sense, photographs bring the construction site back to life and offer a unique view of a large number of facets of the building process. A number of studies have already shown how not only architects (Arnold 2002, Böröcz & Verpoest 2008, Van Goethem 1999) but also engineers and contractors (Bertels 2016, Chrimes 1992, Delhumeau 1993, Krikorian 2011, Leblanc 2014, Van de Vijver 2018) made use of this new medium during this period. The studies mentioned above show how these actors used photographs as a means of representation, propaganda, or to cover themselves in later disputes. Although these studies demonstrate the strong link between this new medium and building practice, there remains a gap in the question of how this evolved in the long 20th century. Especially after the Second World War, the exclusive nature of photographic practice declined and it became an accessible medium for a broad section of the population. Not only did large and international players in the construction sector such as *Bétons armés Hennebique* (1894–1967) now make use of the medium, but also local, regional and national actors. This was also the case with the Kruibeke construction firm Van Laere (° 1938), which is still active today. From around 1945 onwards, Van Laere documented a large number of its construction sites in Belgium. When creating the photographic archive, the firm paid particular attention to their part in the building process, the various phases of the construction, and the final built result to which this led. Construction sites in the province of Antwerp, the company's place of residence, form a large part of the corpus. The archive contains about 120 photo albums, 50 photo folders and 4 drawers with loose visual material, accounting for several thousand visual representations from the company's building history. Until January 2019, the archive remained exclusively in the hands of the company, at which point the Flemish Architecture Institute (VAI) received the photo archive of all construction sites older than 10 years into their custody. The aim of this transfer was to have the whole archive inventoried by a specialized institution and made accessible to the general public in a comprehensive way.

After an initial exploration of the archive, it quickly became clear that this collection offers enormous potential as a historical visual source. On the one hand, this also returns insights into what this medium meant for the actors involved, and on the other hand, it offers us a visual representation of the post-war building process. Despite the promising versatility of these visual sources, there are a few points of interest associated

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with their use. As Peter Burke states in his pilot study, a photograph or image is not an isolated object that offers an objective view of reality. "*To use the evidence of images safely, let alone effectively it is necessary – as in the case of other kinds of source – to be aware of its weaknesses*" (Burke 2008, 14–15). Like any source, photographs belong to their specific historical context. That context had an unmistakable influence on the object itself, the photograph as a material object, and the reality therein depicted. The American historian Jennifer Tucker and cultural historian Tina Campt, in their study of the application of photographs in historical research, advocated approaching visual sources just as textual sources (Tucker & Campt 2009, 4). In other words, photographs have always been made with a purpose in mind, whereby the basic principles of historical criticism also apply.

Taking these points into account, it is essential to subject Van Laere's photographic archive to historical criticism before using this corpus in a follow-up study of the evolution of building practice. In this sense, this article initially tries to provide an answer to the question of what did this photo collection and these images mean for the Van Laere company. How did the meaning evolve over a period of more than 50 years, and is this also reflected in the photo collection? This study also addresses the question of how Van Laere used this photo collection over time, and why the company built up such an extensive archive. By doing so, the contextualization of this photo archive also provides a method that will hopefully encourage us to approach similar archives with the same caution. By answering these questions, the article aims above all to show how the context of creation, use and preservation has an unmistakable influence on what and how reality is depicted in a visual source. The first part of this paper focuses on the theoretical framework of visual source analysis and the historical framework, from which this study derives its methodology and strategy. The second and third parts provide a chronological overview of the history of the Van Laere company, with a focus on its form of management and the most important milestones within the company's activities. This is also framed within the political, economic and social context in which the company operated. The analysis was deliberately demarcated between 1938 and 1989, when the company was transferred to the holding company Ackermans & van Haaren (1876). In parallel, the paper links chronological analysis of the photo archive with a focus on both the materiality and content of the visual sources. This reveals the interaction between the company and its archive, the influence on its creation, and reflection on what can be seen in these images.

2 TOWARDS A DEFINED METHODOLOGY

Within art history and visual studies, the use of visual sources has naturally been part of the research strategy for a long time. In addition, within ethnographic studies, but also sociology, there is increasing attention paid to the use of these types of source. From this interdisciplinary approach, the British geographer Gillian Rose derived a way of dealing with visual sources (Rose 2016). Within her theory, a visual source has four well-defined sides that must be taken into account when approaching it. This takes into account the actors that created the image, where and why as well as the life cycle of the visual source (circulation), the image's custody – how was it preserved, and is there a certain evolution noticeable, the audience and finally the content of the picture. In considering Rose's theory, it becomes clear that it is not only the visual representation of an image that is important. The central thesis of Elizabeth Edwards and Janice Hart revolves around the sense that photographs are not just a two-dimensional format but rather three-dimensional (Edwards & Hart 2004). According to them, the materiality of photographs takes on two broad and interrelated forms. The first form is the plasticity of the image or the photograph itself, where the material properties of one object are viewed in isolation. This is, for example, the quality of the paper, or the format. The second form relates to image presentation, such as the frames or photo albums, which give the isolated photographic objects a certain status. Both the four-sided approach of Rose and the emphasis on the material aspect from Edwards and Hart have been applied in the analysis of the Van Laere archive, which forms the core of the next two parts of this paper. Finally, in addition to this theoretical framework that focuses on visual sources, historical siting and framing are also essential. To this end, the visual sources need to be confronted with other source material, which may reveal possible conflicts or gaps. However, the fully paper contractor's archive dating from before 2010 was recently destroyed by the company. Under Belgian law, reports from the board of directors and documents relating to the organization and internal functioning have to be kept for only five years. For construction files, the legal retention period is ten years. In a clean-up operation, the company thus opted not to keep the older part, with the exception of the photo archive that was transferred to VAI. The institutional and historical framework of the Van Laere company therefore relies mainly on oral sources and limited information from two articles published in local publications. The main oral sources were firstly the grandson of one of the deceased founders who introduced us to the general history of the company along with a Van Laere family member and ex-shareholder who offered details of the management and organizational form of the company. This individual was active between 1962 and 1989 as construction site supervisor, and was able to sketch a good overview of the evolution of the company. Finally, I was also able to interview a former engineer who worked for Van Laere between 1971 and 2013. He provided information about the various projects over time, the site organization and the evolution in the materials and techniques used.

3 1938–1970: THE VAN LAERE PHOTOGRAPHIC ARCHIVE ACQUIRES ITS INITIAL FORM DURING THE FIRM'S BOOMING PERIOD

Shortly after the First World War, Leopold Van Laere (1880–1946) concentrated on building small-scale residential houses. The housing shortage after the war prompted this carpenter to switch to housing construction. However, it was under the impulse of his four eldest sons that the company *Algemene Aannemingen Van Laere en Zonen* was founded in January 1938. During this period, the new business began to focus on large-scale housing projects. To compensate the lack of quality housing, Antwerp, their hometown, was already focusing strongly on social housing during the inter-war period. Van Laere responded to this and a close collaboration developed with the social housing company *S.V. Onze Woning*. During the period 1938–1939, the company was able to build 160 flats in the Luchtbal modernist high-rise district. The Second World War and its political and economic implications threatened to bring Van Laere's activities to a standstill. Out of economic necessity, the company went to work for the German occupier, and was involved in the construction of the Atlantic Wall. As a result of this interaction with the occupying forces, the company threatened to go under in the atmosphere of repression after the liberation in 1944. However, they were partly pardoned due to the fact that the company enjoyed a lot of prestige because they had employed many local people and saved them from forced labor in Nazi Germany. Moreover, during the war they had gained a lot of experience with reinforced concrete, from which they would benefit in the post-war period (D. Van Laere 2020). After the decease of Leopold Van Laere in 1946, his son Florimond took charge of the business. The other five sons held the rest of the shares, and held various positions within the company, from site supervisor to engineer. From around 1950, Van Laere re-established its ties with *S.V. Onze Woning*, among others. There was also constant interaction with prominent Antwerp architects such as Jos Smolderen (1889–1973) and Hugo Van Kuyck (1902–1975). The political and economic situation also contributed to this with, among other aspect, the Brunfaut law (1948) financing social housing. The large social housing project Jan de Voslei (Jos Smolderen) in which Van Laere built hundreds of flats in various apartment-blocks between 1952 and 1956 is one good example. A further example is the high-rise expansion of the Luchtbal social housing district between 1949 and 1964 (Edward Craeye, Louis Clymans, Jozef Fuyen and Hugo Van Kuyck), where Van Laere delivered more than 500 flats (D.C., 1988). A second factor to Van Laere's advantage during the two decades after the war was Antwerp's urban renewal. In 1949, the mayor of Antwerp, Lode Craeybeckx (1897–1976) launched a three-year plan with the intention of realizing a few large-scale buildings for administrative services or a commercial function. Within this context, the Administrative Centre (Renaat Braem), an icon in the Antwerp cityscape realized by Van Laere between 1958 and 1967, is a leading example (Beyers 1974, Genootschap 2008). Finally, in relation to the company's focus on public works, Van Laere also carried out many infrastructural works for the Ministry of Defense during this period. The tense foreign climate of the Cold War certainly played a role in this, with Belgian defense spending rising from 9.8% to 20% of GDP between 1950 and 1952. (Van den Wijngaert & Beullens 1997). Moreover, in 1952 the company had met Harry Steegmans (1919–2001) while working at the Callemeyn Barracks in Arlon, who at the time had been appointed as superintendent of military construction works by the Ministry. They're remained close contact between the company and Steegmans, after which he eventually started working for Van Laere. In addition, from 1948 he was the only non-family member of the board of directors, and was to play a significant role in the further development of the company (H. Van Laere 2020)

It was during this considerable period of expansion that the company began to document its construction sites photographically. From around 1948, a large percentage of the most important construction sites were photographed from start to finish in an almost systematic way. For this purpose, Van Laere mainly called upon the services of professional photographers who visited the construction sites on a regular basis. This can be deduced from the stamps, which in most cases were affixed to the back of the high-quality photo reproductions. For the construction sites in the Antwerp region, it was mainly the local photographers Frans Claes (1913–2005), and in particular Frank Philippi (1921–2010), who were assigned this task. Philippi initially specialized in abstract art photography but, as a professional photographer also welcomed commercial opportunities. For this reason he made photo reportages for numerous Antwerp based companies like *Société Générale Metallurgique* and Ford Motor Company (Bostyn 2011). Philippi is known to have embraced post-war economic growth and technological progress in his work. Art historian Karel van Deuren (1921–2006) also notes that his photographs are strongly conditioned by what they represent. The subject would penetrate the visual aspect very strongly (Bostyn 2011). These characteristics can also be found in most of the photographs Philippi took for Van Laere. Philippi had to depict the construction site, and preferably did so from a position that gives the viewer a large overview of the subject. He usually photographed the construction sites as a still life, as the French historian Robert Carvais categorizes this type of photograph (Soulages & Ferrere 2017, 85–111). With this statement, Carvais means this type of construction site photograph is characterised by their unfinished and material character and above all where man does not appear or only in the distance. The main focus of Philippi was on the progress of the construction site as a whole, with the built result as a sign of progress. The aesthetic possibilities offered by the construction

Figure 1. a & b) Jan de Voslei Antwerp, 1956. The construc-tion site as a still life (Frank Philippi).

Figure 2. a) Photo album of the project Jan de Voslei Ant-werp, 1952–1956 (above). b) Antwerp Mayor Lode Craeybeckx on the first page of a Jan de Voslei phot oalbum (below).

site were also of great importance. The emphasis was therefore not so much on human actions on the construction site, as a result of which these often disappear into the background in his creations (Figures 1a–b).

The presentation form in which Van Laere received the prints between 1950 and 1965 was usually in the form of a photo album. These albums have a businesslike, uniform appearance, with some details of the construction site on the cover, such as the delivery date and the names of the commissioning authority, the architect and the contractor (Figure 2a). Again, it was Frank Philippi who delivered the vast majority of these albums so they contain a representation of his work. This form of presentation enabled Van Laere to emphasize what the firm was capable of, the construction of large projects, with a significant impact on the environment. Each album represented a finished project, with a general overview of how the final result was literally built from the ground up. The fact that several copies of specific albums can be found in the archive implies that the company also distributed them as gifts to the actors involved, which was also confirmed by one of the interviewees (H. Van Laere 2020). This was part of the strengthening of their relationships and contacts, as mentioned earlier. In this sense, it is also striking that some albums on the first page contain a group photo with dignitaries. Lode Craeybeckx, who was Antwerp mayor from 1947 to 1976, for example, appears in some of these group photos (Figure 2b). This presumably represented the approval and involvement of the authorities, which in turn could consolidate the company's reputation for reliability and quality.

4 1970–1989: A TRANSITION WITHIN THE PHOTOGRAPHIC ARCHIVE, UNDER THE INFLUENCE OF THE EVOLVING COMPANY

As a result of the economic crisis of the early 1970s, the government decreased its investment in social housing (Segers 2014). This led to a reduction in business for Van Laere in this sector. From the end of the 1960s onwards, Van Laere gradually started to focus more on civil engineering, such as public water works and road works. In 1966, for example, they were responsible for the expansion of the Fourth Dock in Antwerp, which marked the start of a whole series of works in this sector. It was mainly the expansion plans for the port of Antwerp on the left bank that provided Van Laere with new forms of employment. In the construction of the Waasland port, they were for example involved in the construction of the Kallo lock (1971–1979), the Vrasene dock (1982–1988) and the Berendrecht lock

(1980–1989) which, at the time of completion, was the largest sea lock in the world.

In terms of public roadworks, they had already built a section of the Koning Boudewijn motorway (A13) between 1957 and 1958 but the greatest involvement in this type of work would only follow a decade later. Under Minister of Public Works De Saeger, the construction of highways peaked in Belgium between 1965 and 1973. It was in this context that Van Laere realized its largest road projects, with the construction of a large section of the A3/A21 (1969–1973) as the most important example. This also comprised the construction of tunnels and bridges, including the controversial Gentbrugge viaduct (1966–1970). In addition to civil engineering, Van Laere also continued to focus on other public works. The famous Nekkerhal in Mechelen (1981), for example, was a company project. It was erected in an innovative way as single spans cover both the roof and two wide side walls in prestressed concrete.

In focusing on such a variety of construction sites, Van Laere had to make huge investments in the company. Among other things, a lot of specialized machinery was required but innovative capital-intensive techniques were also part of the cost package. In the post-war period, this mechanization process took place throughout the whole construction sector, particularly from the mid-1960s onwards. It drove many companies towards far-reaching rationalization and specialization, with the emergence of subcontracting for specific tasks such as earthworks (Dobbels 2019, Pesztat & Blieck 2016). Van Laere stepped into this specialization in a certain sense but still insisted on the full execution of the projects using its own techniques and resources (H. Van Laere 2020). This was a major part of the company ethos, control of which remained tightly in the hands of the family, and its own views on business organization (Colli 2003). Harry Steegmans succeeded Florimond Van Laere as business manager from 1978 onwards, with the intention to focus more on rationalization and specialization (A. Hauman 2020). Nevertheless, the day-to-day management remained primarily in the hands of the Van Laere family, which continued to push through its own business strategy. From the mid-1980s onwards, the company found it increasingly difficult to keep its business strategy profitable. They had to compete against competitors who were committed to a fragmented construction process, in which they increasingly outsourced work to specialized firms. In addition, the shareholding was widely dispersed among the Van Laere family over the years with 19 shareholders in 1988 (D.C. 1988). This presented issues with the operational management of the company. In 1989, therefore, the family partners decided to sell their shares to the holding company Ackermans & van Haaren, which has owned the company ever since (H. Van Laere 2020).

This evolution within the company also had a noticeable influence on the photographic archive that was established roughly between 1970 and 1989. In around 1966, for some unknown reason, the collaboration with the former house photographer Frank Philippi came to an end. However, the company chose again to have its construction sites predominantly documented by professional photographers. These were mostly photographers from the Antwerp region, such as Guido Coolens (1930–2000), or occasionally from another region when the construction sites were too far from their home town. The fact that there were several photographers at work also means that the focus on what is depicted is much more heterogeneous than before 1970.

Figure 3. Water barrier Scheldt quays Antwerp, 1978. Inter-action between man, machine and technology. (Photographer unknown).

Nevertheless, it is clearly noticeable that the construction sites were henceforth no longer mainly depicted as a still life with the emphasis also shifting to the techniques and equipment in use. Aerial photographs of construction sites also played an increasingly important role, in which Guido Coolens, as a specialist aerial photographer, provided a certain share (Figure 3). These not only showed the grandeur, but also, for example, the organization and the site infrastructure. In other words, the construction site was no longer reduced to a mere flawless process of progress towards the end result, as was the case with Philippi, but rather as a place of interaction between man, machine and technology (Figure 4). Whether Van Laere itself was responsible for this shift is not entirely clear. From correspondence between Guido Coolens and the company, however, it can be deduced that Van Laere had the final decision about which negatives the photographer eventually developed into prints.

The way in which Van Laere stored and presented its photographs in this later period also shows clear evolution. From around 1970, the use of photo albums in this sense almost completely disappeared. From then on, the developed copies were placed in hanging folders, which in addition to the photographs also regularly contain various forms of documentation such

Figure 4. Kallo lock Antwerp, circa 1975. Van Laere is responsible for the complete execution, with its own techniques and resources. At the back, the river Scheldt is clearly visible, with Van Laere's very own loading quay, its own concrete plant, and its own infrastructure network, techniques and materials. (Guido Coolens).

as newspaper articles (Figure 5b). This means that the construction site photos now had a documentary function for the company, rather than the presentational function they previously fulfilled. The increased mechanization and use of innovation techniques on the construction site will certainly have played a role in this. The photographs served as the company's memory and offered an opportunity for self-evaluation. In addition, they also provided some form of evidence and cover in the context of increasingly strict building regulations.

However, the presentational function of photographs did not disappear completely for the company but was now mainly limited to an overview photo of the built result. In this sense, Van Laere had several short portfolios published in this later period, each with a short description of the project and a full-page photograph either of a later stage of construction or the built result (Figure 5a). Another good example are the various greetings cards and Christmas cards, usually taken from a bird's eye view, which can be found in the archive (Figure 5c). These again served to maintain contacts with the various actors involved. Thus, the visual representation of the construction site with its increased complexity became an internal matter with the public seeing only the built result. A single glance at the built result now had to represent the ability of the company in a construction world where it had become increasingly difficult to consolidate and survive.

5 VAN LAERE AND ITS VISUAL ARCHIVE

Throughout the analysis, it became clear there is a certain link between, on the one hand, the evolution of the company and its context and, on the other hand, what was depicted and in what way. Not only did the content of images evolve along with it but also the form of presentation, the way in which they were preserved, and especially what the photographs meant to Van Laere whether as visual representations or as material objects. Between 1948 and 1970, Van Laere's construction sites were mainly depicted as a still life and as aesthetic objects which, as part of a permanent and infallible process, led to the built result as an example of the growth and progress of the company at that time. Frank Philippi, the company's in-house photographer, however, played a large role in this. The photo albums, recording the process from beginning to end and consolidating the company's capabilities, confirm this. The distribution and public character of these photo albums also had to convince Van Laere's

De Direktie van de n.v. Algemene Aannemingen VAN LAERE
te Zwijndrecht (Burcht) wenst U een vrolijk Kerstfeest en een gelukkig Nieuwjaar.

NIEUWE GROENTEMARKT — MECHELEN

Figure 5. Gasthuisberg Hospital Leuvenas depicted in a Van Laere portfolio (above left). b) Documentation folders with photographs (above right). c) A 1981 New Year's card from the construction company Van Laere shows the finished project Nekkerhal in Mechelen. A typical photo by Guido Coolens, taken from a bird's eye view (below).

crucial networks of the firm's status. Alongside the mechanization, rationalization and specialization of the construction industry, Van Laere's photographic archive also evolved between 1970 and 1989. The construction site became complex with a transformative close relationship between man, technology and machine. In the photographs, the infallible character of the construction process partially disappeared, evolving towards a realistic representation of a complicated reality. Van Laere, who kept full control of the building process within their business strategy, saw this as a good way of documenting and evaluating the methods, techniques and organization used. On the other hand, the public visualization of the built result had to confirm the company's ability and the good reputation it had built up over the years by means of one powerful image. Finally, this contextual and content-related analysis of the Van Laere visual archive also confirms the proposition that photographic material is and remains a complex source to deal with. It also proves that an in-depth preliminary study is needed to get a grip on such an extensive archive. As Burke puts it, the images we see in the archive are not objective witnesses. Like a written source, they are highly dependent on the context in which they were created. A context that should certainly be taken into account when further interpreting the images in this sense.

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Open session: Building actors

History of Construction Cultures – Mascarenhas-Mateus & Paula Pires (eds)

Building the ephemeral in Turin, capital of the Savoyard states

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ABSTRACT: The extensive literature on ephemeral architecture in the modern age is rarely encountered in building historiography. Yet even the architecture of festivities or other recurrent occasions, especially in the capital cities of the *ancien régime*, demanded complex technical and decision-making processes just as much as the construction of palaces of more lasting importance. Such was the case we would like to present here: the celebrations of the wedding of the Savoy prince Vittorio Amedeo III with Maria Antonia Ferdinanda, *infanta* of Spain, which was celebrated in Turin in 1750. This paper looks at the creation of these decorative structures as strictly regulated processes, interwoven with the politics of the Savoyard kingdom just as much as the construction of palaces and strategic fortresses scattered throughout their territory. Erecting these temporary structures, therefore, required meticulous consideration, evidence of which can be found by delving into the archival sources.

1 BUILDING THE EPHEMERAL IN TURIN

1.1 *Ceremonies in the age of absolutism*

In the centuries of absolutism, Europe had a passion for rituals and ephemeral representations. In particular, they were set up on the occasion of significant dynastic events such as weddings, funerals and ascensions to the throne. Besides, plenty of religious and civil events were sponsored by local authorities such as municipalities. These multiple celebrations may have involved churches, palaces or the entire urban space (Fagiolo 1985, 2006).

If we look at the States of the House of Savoy, located in the geographical area straddling the Alps between France and Italy, there is now wide-ranging historiography on the subject (Devoti & Defabiani 2006; Gianasso 2006; Grosse 2016; Ieni 1989). Scholars above all highlight the aspects of political legitimisation, the iconographic and iconological dimensions, the historical-institutional facet, and also the contribution to a broader recognition of cultural contexts and the social and cultural history (Peyrot 1965). The literature traditionally makes many references to specific printed sources, particularly the *Relazioni* that, especially in the 17th century, describe and accompany ephemeral events, perpetuating them over time. But, above all, the literature defines the conceptual dimension of ephemeral events, emphasising the moment of conception, with its symbolic and political charge in which the celebrative intentions of the patron are expressed, or what Jesuit Father Claude-François Ménestrier called, in the second half of the 17th century, the *pensée* of the feast. However, it is the same author who reminds us how the conception of the event constitutes only the first moment of a complex process: "Enfin il y a 3 choses à considérer dans un dessin, la pensée, l'ordonnance, l'exécution de la pensée c'est-à-dire qu'il faut un homme d'estude, un ingénieur et des ouvriers pour ce sorte d'entreprises" (Carandini 1997; Ménestrier 1669).

The *ordonnance*, i.e., the actual design of the decorations and structures, which also includes the arrangement of the architectural orders and decorations, evidently requires subsequent execution by multiple workers and professional figures, working under the orders of an architect or engineer. It is precisely this type of organisation that we also find in the case of the festivals held in Turin, capital of the Savoyard state (Romano 1995). This system was a common element in European culture and not just local. In as early as the first decades of the 17th century, the Court in Turin was already keeping abreast of the most important international celebrations (Rabellino 2006; Rasetti 2006). For example, on the occasion of the death of his wife Micaela Catalina of Habsburg, Duke Carlo Emanuele requested organising the religious ceremony by consulting "the books of the funerals of emperor Charles V, king Francis and other kings of France, which can be found in our library" (Cozzo 2001).

Although the architectural and artistic dimensions of festivals received more attention in recent years, in addition to their symbolic values, scholars did not pay the same attention to the construction phase, which

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Figure 1. False *façade* of San Carlo Church (ASTo, Corte, f. 65r, 1750).

is often considered a secondary element. The construction of ephemeral architecture is still a field of study that has not been much explored. Thus, what are the exchanges and relationships between the ordinary building site and the ephemeral architecture site? What are technological, economic and professional resources involved? What are the rules for standardising and controlling works that must have been completed in a few weeks, if not in a few days?

Archival documents can help us answer these questions, even if still provisionally: large-scale ephemeral structures are public worksites often documented with an abundance of textual and iconographic sources related to the construction. Also, contemporary descriptions, reports of visits and engravings allow us to read the scenography and spectacular results of the machines and built architecture. A paradigmatic case is the celebrations for the marriage of Prince Vittorio Amedeo, son of Carlo Emanuele III, to the *infanta* of Spain Maria Antonia Ferdinanda (1750). Many simultaneous works made it possible to set up "fires of joy" and "illuminations" in different parts of the city as well as in aristocratic palaces (Figure 1).

Several places in the city were equipped with spectacular *trompe-l'oeil* to complete projects that were still in progress: among these were the façade of *Palazzo Madama* towards *Via di Po* and the façade of the church of *San Carlo* in the square of the same name (Canavesio 1992).

This was not only a matter of setting up a temporary scenography, but also prefiguring the work in progress on the capital city, an always open and long-lasting construction site.

2 THE CONSTRUCTION SITE OF FESTIVITIES IN TURIN

2.1 *The illumination*

An interesting example of an ephemeral construction site was reported in 1750, for the celebration of the marriage of the Savoy prince Vittorio Amedeo III and Maria Antonia Ferdinanda, the *infanta* of Spain. The wedding took place in Madrid with solemn celebrations, which included events and theatre performances. The *Giornali di Tamietti* (Tamietti 1750) and Belmond's engravings are memories of these majestic celebrations. Belmond was the royal engraver and between 1751 and 1761 he represented three main events of the ceremonies (Bertagna 1981): the *fochi di gioja* (fireworks) at *Valentino*, the false façade of the Castle (Madama Palace) towards the *Contrada Nuova* (*via Po*), and *via di Dora Grossa* (today *via Garibaldi*). The leitmotiv was the "illumination", a term used to indicate the ephemeral embellishment to illuminate streets and palaces for three consecutive days and which at the same time enhanced the architectural features along these same streets.

The concept of space and festivities in the Turin of the Baroque Age was redefined and gave birth to a new tradition. Space was no longer linked to the ceremonies of the 17th century (Rasetti 2006), but mainly based on the glorification of the capital city by illuminating its buildings with lights and candles placed on the façades according to well-defined schemes (as for the marriage of the prince Carlo Emanuele III to Anna Cristina Sulzabach in 1722, with "fires of joy" and "illuminations"). The *mastro tollaro* (lead worker), Bernardino Viani, from the state of Milan and winner of the tender, was charged to light the capital city with the provision of 10,000 sheet metal lights. These lightings were to be following the model shown and approved by the Council of Buildings and Fortifications at the price of 2 *monete*, 6 *denari* for each lighting (ASTo, 20 March 1750, f. 76 r). The contractors Giovanni Pietro Gobbi and Antonio Maffei were to be in charge of the decorations to light up the *Contrada Nuova*, including the square in front of the Castle (Madama Palace) and *San Carlo* square. The amount of material required was certainly high: for the *Contrada Nuova*, the provision was for 268 coats-of-arms for the mezzanine level and the same number for the upper floor (*piano nobile*) and the top floor at the price of £1, *soldi* 2 and *denari* 6. On the other hand, the material required for San Carlo square was 118 coats-of-arms for the arches, also at the same price as those for *Contrada Nuova*, 59 candlesticks to be placed above the intercolumns at £1, *denari* 10, and finally 118 stars on the top floor at £1, *soldi* 2 and *denari* 6 each (ASTo, 20 April 1750).

The instructions from the first royal architect, Benedetto Alfieri (Bellini 1981), meticulously described the construction of the various pieces of lighting as well as their exact location. The coats of arms and stars had to be built following the sample model. This must have been done in a circular or triangular shape and fixed with pitons to an iron ring to

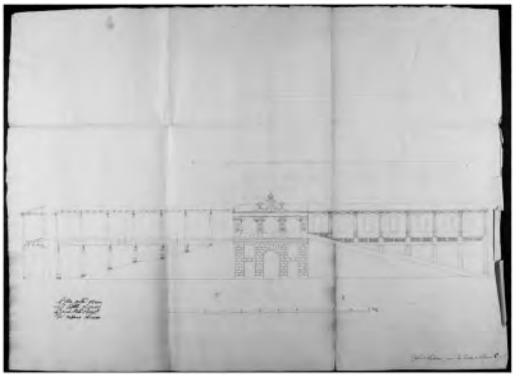

Figure 2. Spectacle for the *fochi di gioja* (fireworks) facing the *Valentino Reale* (ASTo, Corte, f. 71r, 1750).

be suspended and placed between the openings of the arcades. On top of the barriers of buildings, they had to put chains of lights, while on the sides of the windows, there were coats-of-arms with burning candles for three consecutive evenings. The building contractor had to make sure that the lighting lasted for at least three hours, soaking the wick of *acquarasa* (essence of turtine) to ensure this. To facilitate repeated re-filling of the lighting, the contractor had to bring with him metal sheet jars filled with liquefied animal fat. The jars had two holes for pour into the wick or have available fat in a dough form that had to be inserted with a sheet metal spoon.

2.2 *Ephemeral for the Valentino Reale*

Although lighting adorned various locations in Turin, the spectacle at *Valentino* was undoubtedly one of the most evocative because of its natural position set in the theatrical ambience of the Royal Palace. The illumination was set up along the roads that led to the *Valentino* where the theatrical performance took place (Cornaglia 2006) and stretching uphill to the other side of the river Po, where the fire machine was located. (Figure 2).

The painter Giovanni Battista Alberoni won the contract for the production along with the *Valentino* for the amount of £2,000, including testing the machine, and had to strictly follow the first architect's instructions (ASTo, 12 April 1750). These instructions defined the design to be drawn, i.e. frames, ashlars, statues, weapons and ornaments which embellished the fire machine. The fire machine was set up for the occasion at the temple of Hymenaeus, adorned with columns and statues, placed on a bridge parallel to the riverside, and surrounded by lights. At the background two rocky mountains were to be painted to represent the Alps and the Pyrenees from which flowed respectively the two rivers Po and Ebro (ASTo 11 March 1750).

Two large boats and others of smaller dimensions floated on the river Po, and were loaded with fireworks, intended to simulate a naval battle.

The workmanship of the two largest boats was accurately described in the *partiti* (contracts), signed by the craftsmen at work and kept at the State Archives of Turin. The vessels had to be made of wood, with bas-reliefs of trophies painted in oil using different colour tones of blue, red and yellow (emblems of the Crowns of Spain and Sardinia) with their shading, as well as ropes and sails, all painted of the same colours.

The construction of the boat skeleton, to be made according to the model built by the artillery officer at a scale of twenty fourth of *piede liprando* (an archaic measurement unit used in construction) (0.513 m), was entrusted to the carpenter Giuseppe Salazza for a price of £1,230. The vessels had to be equipped with well-straight trees, proportionate to their size, made of wood, well-seasoned and without any defect; they also had to be equipped with ropes, flags and all ornaments, as indicated in the model.

The contract also included a hall inside the *Valentino* for the carpenter Salazza to be able to collect and store the wood, nails and everything else needed for the construction of the boats. The *mastro indoratore* (gilder) Gaetano Leveghe was entrusted to decorate these boats on 9 March 1750 and had to carefully follow the model following which it had to be applied uniformly and proportionally. The construction of the vessels was set at the price of 30 *zecchini* each (about £10). It included the testing of the previous work, and the supply of the canvas necessary to cover the vessels to keep them safe in case of sudden rains as well as to prevent the painted decorations from deteriorating in the sun (ASTo, 16 March 1750).

2.3 *The construction site for the fireworks exhibition*

To ensure a fully embellished ceremonial space, there was the installation of a stage with side loggias on the riverbank of the Po to enjoy the fireworks exhibition. Giovanni Battista Ollivetto, who was from the Andorno valley, today known as Cervo valley, and Pietro Antonio Ostano, also from the Biella area, were entrusted with the task of building the stage with side loggias. Their work was to follow the design of Carlo Aliberti made according to the indications of the first royal architect, Benedetto Alfieri, and accompanied by the measurements provided by Benedetto Feroggio. Ollivetto and Ostano had won the contract by submitting a £1,950 reduction in the tender, thus reducing the price for the loggias to £3,000 (ASTo, 20 March 1750). The two craftsmen were responsible for the provision, at their own expense, of all the wood. The instructions indicated the quality of the wood with the quantity defined by Feroggio's calculations as well as all the nails and the metalware as per instructions.

The Alfieri's instructions (ASTo, 17 March 1750) describe the materials indicating the origins of the wooden elements (the Province of Susa) and their quality. The *remme* (beams) had to be in oak; the *paradossi* (strut) had to be necessarily made of *malegine* (larch), while the strips for the formation of the vault

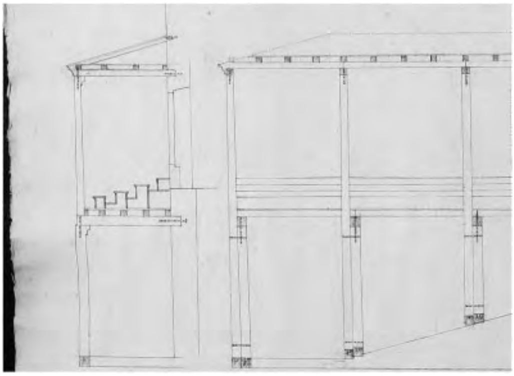

Figure 3. Detail of the temporary structure for the spectacle of boats on the Po by Carlo Aliberti (ASTo, Corte, f. 71r, 1750).

at the end of the closed loggia should have been made in *albera* (poplar). The building contractors provided nails excluding the brackets to hold the beams, which were instead provided by the Office of Factories and Fortifications. They also offered the grey waxed canvas to cover the loggias, which had to be secured with iron blades attached to the wooden beams, also decorated with ornaments and paintings.

All operations to be executed were then accurately reported: the loggias had to be built onto the two staircases located at the sides of the *Valentino*, starting from the side towards the river Po, as shown in the drawing (Figure 3) and accordingly to established measurements.

Works were to continue by drilling holes into the masonry to securely accommodated the beams, secured with iron *grappe* (brackets) at least 2 feet long (1,026 m) and nailed to the beams with iron plates to ensure maximum safety. Then, the wooden poles had to be inserted into the well-flattened ground, two for each span, always of the dimension dictated by the calculations of Feroggio. The floor at the base of the loggias and the scene was supported by poplar planks and joined together with at least three nails each. Both the stage and the loggia cover had to be well fixed into the masonry with two iron *lamme* (iron plates) each, which in turn were secured by nailing the timber together.

After this operation, seating was built, made of poplar wood, smoothed and well-polished on the upper side, measuring at least 10 ounces (0.42 m) in width and 12 ounces (0.50 m) in height. The following step was the construction of the parapet, and the pilaster, made with fine poplar planks and long beams stopped by uprights. With at least five nails, all well-fixed, for each axis, above there had to be an axis affixed, flattened and nailed, at least 3 ounces wide (0.126 m).

For producing the wooden rib, wooden strips had to be fixed at a maximum distance of 6 ounces (0.252 m) from each other to support the ceiling. The waxed canvas was fixed with iron nails. As specified in the contract, the two craftsmen Giovanni Stefano Ollivetto (from Monforte d'Alba, Cuneo) and Giacomo Mercandino (from Pralongo, Belluno) were in charge of the provision of the grey coloured waxed canvas for covering the loggias (ASTo, 2 April 1750). This required 800 *rasi* (479 m) of grey waxed canvas, the quality of which was verified by the Office, at a price per *raso* of 17 *soldi* and 6 *denari*.

The instructions also specified that wood and tools were to be taken on-site to execute the works. A guard would have watched over the materials to prevent any robbery. At the end of the ceremonies, everything had to be carefully disassembled and, as indicated in the contract, the companies had to assign the materials to the Office, which would store them in the Royal Warehouses. Before settling the final balance of the payment, the building contractor had the following tasks: replace the *chiassili* (shutters) in the windows after having removed them to accommodate the spectacle; place the parapets back in front of the windows; ensure the closing of all the holes made to fix the wooden stage to the palace; and repair any damage that might have inadvertently happened.

The spectacular repertoire of festivities realised at the *Valentino* would have ended, with scenic effects and decorative settings of royal munificence according to the expectations of the royal court.

3 CONCLUSIONS

3.1 *The importance of studying ephemeral construction sites*

Analysing the documents, the first aspect that emerges concerns the articulation of the design and administrative process: in the case of the 1750 festivities, both mainly functional structures, such as the stages for the public, and elaborate decorations were built whether painted or with sculptural sections: machines for the fireworks, large facades painted on canvas that concealed Filippo Juvarra's two unfinished buildings and required the intervention of highly specialised artists and artisans. In all of these cases, even the simplest, every aspect of construction was controlled and managed with the same attention as that devoted to the construction of a royal palace: the entire administrative process – from the project to the tender, to the contracts with companies and workers, to the verification of the work in progress, to the final acceptance and verification that precedes the payment – followed the usual standards of rigorous control typical of the Savoy bureaucracy (Burgassi & Volpiano 2020). In the design phase, complex architecture models would be prepared, such as that made by an artillery officer for the construction of the two firework ships. Each piece of the woodwork for the construction of the supporting structures of the curtain walls was also rigorously designed and dimensioned, with precise indications of the different types of wood to be used. The accuracy of the design also included specific provisions for the supply of material and special permits to procure it, even if located some kilometres distant from the capital city: "In case of need, the said *Impresarij* will be granted the licence to extract from the Province of Susa the quantities of Larch beams that will be necessary" (ASTo, 20 March 1750). The expression of this control is evident both in the always present executive, graphic drawings in scale (in *trabucchi*, an archaic measurement unit used in Piedmont during the old regime). These were the indications the contractors were provided by the first royal architect Benedetto Alfieri in the *istruzioni*. He coordinated the work and designed the façade of *Palazzo Madama* towards the Po. For the other works, he used the collaborators mentioned above Prunotto, an aide of Filippo Juvarra, and Aliberti, who was close to the world of theatrical scenography and figures like the painter Galliari who painted the large *telleri* (canvas).

It is therefore clear that strict control by the royal architect was essential to managing a multi-site construction programme. The complexity is not negligible, and the costs were very high: the whole festivities cost the public purse more than £335,000 and, for example, just the balcony decoration for the public at the Valentino was estimated at £2,000. By way of comparison, a few years later, in 1754, the refined wooden floors in the royal apartments of the *Venaria Reale* palace cost no more than £170 each (for the *Camera di Ricevimento* or Reception Chamber of HRH the Duke of Savoy £160); the precious polychrome marble floor of the new gallery cost, and including polishing and installation, slightly over £7,000.

As seen from the tender documents, materials were supplied by the contractors, although not always: canvases for the painted backdrops and metal brackets to connect the beams were always provided by the *Regi Magazzini*. The contracts of the *capomastri da bosco* (carpenters) often provided that the materials, after use, if still usable, would return to the property of the contractors. The necessity of assembly and disassembly allows us to intuit a rather complex logistics for the storage of materials (as seen, a particular room was set up for this purpose in the *Regio Palazzo* del *Valentino*).

There were still other costs, which extended beyond the end of the celebrations. Once the temporary structures had been dismantled, the documents remind us that it would have been necessary to repair any damage to the walls caused by the anchoring of the beams. In some cases, there was also the matter of compensating private owners who had had their properties temporarily occupied.

In conclusion, the building site for the ephemerals and the ceremonies also represents an ongoing research site that deserves further investigation.

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History of Construction Cultures – Mascarenhas-Mateus & Paula Pires (eds)

The business of the early consulting engineer: The case of Thomas Telford (1815–1834)

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ABSTRACT: Historical research on early consulting engineers in Britain has concentrated on their projects as the profession developed from the late 18th century, but little has been done to study their financial affairs. Thomas Telford (1757–1834) dominated British civil engineering 1821–34. His career is well-known, yet the management of his business affairs remains largely unknown. Using recent research into the history of consulting engineering as a background, this paper considers what Telford's surviving papers tell us about his income and business focusing on the last 20 years of his life.

1 INTRODUCTION

Little work has been done on the income and wealth of professional engineers of past generations, the focus generally being on their engineering achievements and ideas, and how they organized their projects. General appreciation of engineers has followed the dictum of Wren "Si monumentum requiris circumspice". The personal life and business success of engineers has generally been glossed over. One reason for this neglect of "filthy lucre" is a shortage of evidence, particularly true for early engineers, business records rarely surviving the death of the protagonist. Although account books survive for parts of the careers of a number of engineers, little attempt had been made to pull this evidence together before the publication of the first volume of the Biographical Dictionary of Civil Engineers (Skempton 2002).

For that work authors were encouraged to share information on fee income, value of projects, and wealth at death. It was then possible to identify typical salaries and fees charged over the period 1500–1830 and beyond. It was also possible to draw up tables of relative wealth (Chrimes 2004, 2019). Work was done more recently on engineers' businesses as part of a history of consulting engineers (Ferguson & Chrimes 2019). However, it remains difficult to establish how much money was actually earned each year by early engineers, and the nature of their professional expenses. This paper seeks to do that for Thomas Telford.

2 THOMAS TELFORD (1757–1834) AND BRITISH CIVIL ENGINEERING AROUND 1800

Telford was one of the leading British engineers ca. 1795–1834, and was also relatively unusual in coming from a humble background, working up from a journeyman mason, to an aspirant architect, and ultimately becoming the first President of the Institution of Civil Engineers (Gibb 1935; Glover 2017, Paxton 2007; Penfold 1990; Rickman 1838; Rolt 1957; Smiles 1861). He was responsible for over £5.6 m of works (Skempton 2002: 696–7) – including over 1900 km of roads, 1100 bridges and numerous canals and harbours – and surveyed many more. It was the equivalent of being in charge of a modern country's motorway and high-speed rail network. Beyond the British Isles, he advised on projects in India, British North America, Sweden, Switzerland and the Russian Empire.

The civil engineering profession had emerged in Britain in the second half of the 18th century as the volume of work from industrial clients and the demand for infrastructure enabled individuals to make a full-time living as a consulting engineer for the first time (Skempton 1996). Thanks in part to the leadership and example of John Smeaton (1724–1792), the concept of a profession of civil engineer took hold (Skempton 1981) with the idea of what later became known as consulting engineers providing independent advice to clients – without a financial interest in products associated with their recommendations, or competing for fees with each other.

As the profession grew in status so did income, even allowing for inflation, with fees rising from a guinea a day around mid-century to 3 guineas in the 1780s, 5 guineas in the late 1790s, and 7 guineas a day from around 1810 for John Rennie, soon followed by Telford. The leaders of the profession generally led the way, and were tempted by full-time salaries to try and secure full-time services. This was never likely to work for the most able and in-demand, as the Liverpool and Manchester Railway directors discovered with George Stephenson in the 1820s: £1000 p.a. for exclusivity could not stave the temptation of other clients. More normal was a high part-time salary, such

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as John Rennie's £500 for 90 days' service at London Docks in 1801. Despite these attractions, many engineers also practiced as architects, had other business interests, and took salaries from a number of clients.

In Telford's time, it was still a new profession, and one in which he recognized the difficulties in obtaining an adequate education and training, a motive in 1818 for the establishment of the Institution of Civil Engineers of which he soon became President.

Telford's eminence at such a formative time is justification enough for studying what we know about his business affairs, given that business records for the last 25 years of his career have survived – at least in part – in the National Library of Scotland. This has made it possible to get a feel for his sources of income and his expenditure over the period. One cannot be sure how typical he was, but it is starting point. Unlike other engineers of the period, he had no other obvious business interest to support him, nor inherited wealth. The estate of over £34,000 he left at his death was accumulated through his work as a civil engineer.

3 TELFORD'S WEALTH

The traditional picture of Telford's wealth and lifestyle is of a man living modestly: "His wants were few, and his household expenses small; and though he entertained many visitors and friends, it was in a quiet way and on a moderate scale" (Smiles 1861, II: 487). Smiles likened his income to that of "the resident engineer of any modern railway", and indeed suggests his investment income was bringing in £800 p.a. at the end of his life (Smiles 1861, II: 489). However, this is almost certainly based on an erroneous estimate of his estate of ca. £16,000 (bank rates at the time fluctuated 4–5%). His final estate was more than twice that, and the lower figure is based on an aggregate of the bequests in his will. A decade earlier his pupil Joseph Mitchell estimated Telford was living at the rate of £1200 p.a., consistent with the house he was leasing. Thereafter he was busier than ever.

From 1790, his income was made up of salaries, consultancy fees, and investment income, and his expenditure was a combination of professional outlay, support for friends, and household expenses.

4 TELFORD'S INCOME BEFORE 1810

Telford's early work as a mason and foreman would have paid perhaps 1s 6d-8d (ca. 8p) a day in Scotland (18d according to Smiles 1861, II: 301), and up to 3s 6d (ca. 17.5p) in London. From 1787, he took on some of the duties of a county surveyor in Shropshire, starting with the supervision of the construction of Shrewsbury gaol for £60 p.a. He also began to advise on the County's bridges, earning fees of £3–£11 for advice on repairs (Cross-Rudkin 2007). He was paid a salary of £200 over two years for Mountford Bridge (1790–92), paying for the clerk of works out of this. His presence in Shropshire enabled his appointment as "General agent (…) engineer (…) overlooker of the Works" on the Ellesmere canal at a salary of £500 p.a. in September 1793, William Jessop being consultant. Again, this included the expectation he would pay for the overseers from his salary; he soon changed this, taking a reduced salary of £300 to avoid this cost, reduced again to £100 p.a. after the Canal was opened in 1805 (Brown 2007). Thereafter, appointments followed thick and fast.

Table 1. Typical annual incomes c. 1800

Agricultural labourers	£30
Canal Navvies	£40
Artisans	£55
Clerks	£75
Lesser clergymen	£120
Shopkeepers	£150
Lower public offices	£200
Lawyers	£350
Gentry living on income	£700
Lesser merchants, manufacturers, leading public servants	£800
Knights and esquires	£1500
Eminent merchants and bankers	£2600
Peers	£8000

By 1803 he was charging 3 guineas a day in fees to public bodies, and 5 guineas to private clients. Much of his early work for the British Fisheries Society was "free" – probably at cost. However, this led to paid work for a series of Commissions – notably for Highland Roads and Bridges, and the Caledonian Canal, and similar work in Ireland from 1803 (Cox 2009).

Among some clients there was from early in his engineering career a concern about the time he was devoting to his salaried positions, and the frequency with which he asked people like the Ellesmere Canal resident engineer Thomas Stanton to undertake other local projects for him (Brown 2007). Yet before Jessop's death in 1814 he had full charge of their joint works and, thereafter, while he worked with other leading engineers, he was generally the senior engineer himself.

5 SALARIES AND WEALTH AROUND 1800

There have been limited studies of wealth and income in the early 19th century in Britain, drawing on income tax returns and contemporary accounts. The most serious research has focused on the very wealthy and the labouring poor rather than the comfortably off. The broad-brush figures in Table 1 provide some context for the discussion that follows (Lindert 1982):

Unsurprisingly, assistant and resident engineers of the period were paid £160–£500 according to the size of the project and their responsibility. One can see that already by 1800 Telford would have been earning more than that from his combined salaries for his canal and local government appointments. It is intended below to try and put more flesh on the financial bones of his consulting engineering business.

6 LONG-TERM GOVERNMENT APPOINTMENTS

The most accessible information on Telford's income is provided by the published reports relating to central government appointments. Telford secured a number of such appointments in the early 19th century following his work on government reports and inquiries. After his initial surveys, a system was established to carry out an agreed programme of works supervised by Telford-appointed supervisors or assistant engineer on long-term contracts, many of whom he already knew when the appointments were made, including the fellow Eskdale man Matthew Davidson on the Caledonian Canal, and his former pupil William Provis on the Holyhead Road and Menai Bridge. In addition to their salaried work, Telford often used them to undertake surveys or reports on other prospective schemes, paying them out of his own account and reclaiming the money from clients, including the various commissioners noted below. These three principal appointments would have paid him £400–£1000 p.a. over 25 years.

6.1 *Caledonian canal (1803-)*

Telford's appointment as Engineer was initially shared with William Jessop the senior consulting engineer, and construction was largely completed by the time of Jessop's death. Telford's total earnings were therefore constrained by his shared position. For the Caledonian Canal he was paid £667 18s 2d for preliminary work, and £2464 7s 1803–13, a period when he was making two visits a year. As will be seen from the notes below, this was latterly largely for a tour of inspection and organizing the payment of salaries to various supervisors. His managerial role has been studied in some detail by Penfold (Penfold 1980, 129–150).

6.2 *Highland roads and bridges commissioner*

Telford's role was expanded as the Commissioner for Highland Roads and Bridges took on further responsibilities to embrace almost all of Scotland's pre-rail infrastructure. That said, most of the heavy expenditure was in the early years, rising from £115 2s 3d in 1803 to over £600 p.a. 1810-15, plus expenses of several hundred pounds p.a. The volume of work warranted paying for Telford's own clerk 1810-16. Most years in that period Telford was paying out several thousand pounds through special Bank of Scotland accounts discussed further below (Commissioners 1828, 14). That account was closed in 1827. At that time his annual inspection was charged at £116 2s.

6.3 *Holyhead road commissioners (1815-)*
(Select Committee 1830, 45)

As with the Highlands appointment, Telford's work was sustained by added responsibilities for harbours and road improvements beyond the initial scope. From his initial appointment in July 1815, he was paid 5 guineas a day plus 2s a mile. By 1830 he had been paid £6295 5s, plus £2057 2s 6d in expenses, excluding the monies he reclaimed for his assistants' charges for additional surveys.

From his surviving papers we can cite the example of the Ketley-Chirk Road to get some understanding of how he managed such new work. In January 1830, he paid £4 10s to Thomas Casebourne to prepare the drawings of the plans and sections in the office for six days' work at 15s a day (NLS Acc F20), while a junior draughtsman, Francis Dodd, was employed for seven days as 7s a day, £2 9s in all for copying the drawings and report (NLS Acc 19973 F64). There would also have been a bill from Arrowsmith, probably £2–£3, for engraving the plans for the accompanying printed report, but the receipt does not survive. The actual survey was carried out by Macneill, then the Superintendent of the Holyhead Road in England (Telford 1830).

6.4 *Exchequer bill loan commissioners*

In 1817, Telford became the Engineer to the newly created Exchequer Bill Loan Commission, a body created to tackle unemployment after the Napoleonic Wars through investment in public works. It provided him with a steady stream of consultancy work for the remainder of his life – of the order of £600–1000 p.a. It involved the approval of over 40 projects and turning down applications for others (Skempton 2002: 690–691).

7 TELFORD'S BUSINESS RECORDS

In the year before his death, Telford's assistant George Turnbull drew up a catalogue of his papers and drawings with the intention that those his executors considered of interest would be passed to the Institution of Civil Engineers (Turnbull 1891). While that was to happen with most of his drawings, his business papers and correspondence had a more troubled history, some indeed being retained at the ICE, but others disappearing from view and not resurfacing; some in a very parlous state, in the 1970s. These are now to be found in the Telford collection at Ironbridge Gorge Museum, and as the Telford collection in the National Library of Scotland. One of the groups of papers there includes surviving papers from Telford's bank accounts, and receipts and invoices from various of Telford's suppliers, assistants, and landlords (NLS Acc 19973), while others give an insight into his relationship with his clients.

7.1 *Telford's bank accounts*

Statements from Telford's bank accounts with the Bank of Scotland survive for the years 1813–1819, and relate to a personal account, and a "public" account through which he was empowered to pay supervisors and other assistants for their work on various Scottish works (NLS Acc F136–F140). It is evident he must have had other bank accounts, most probably one in Shrewsbury, and an arrangement with a bank in London as the Bank of Scotland did not have a London branch at that time – Coutts is mentioned occasionally, but probably as a conduit of government funds from London.

Expenditure through these accounts on Scottish roads etc. varied between £1100 in 1819 and £7100 in 1815. Telford's income included £856 5s 2d from the Swedish Government in 1816 (he had already billed them £416 10s 6d in 1813 for his original surveys from 1808-), In 1818, credits included many small payments under £100 from unspecified Scottish sources, and transfers from Coutts of £1503 twice a year. In December 1817, Telford received outstanding payments for survey work on the Glasgow Carlisle Road of £636 17s 4d, suggesting he had deep pockets. Two years later he received a payment of £453 19s 6d. The only other personal credit that year was for £500. Typically, he withdrew £50–100 for expenses when he visited Edinburgh. An unusual set of transactions related to the well-known technical author Peter Nicholson (1765–1845). Telford lent him £400 against the security of his Glasgow house which was redeemed in 1818, earning over £45 in interest, perhaps to enable his move to London. The pair had worked on a number of projects, including the *Edinburgh Encyclopaedia*, in which Telford was a subscriber, and the bank accounts record Telford meeting calls of £200 on its shares. Both these transactions reflect a well-to-do man, with healthy bank balances, earning interest of ca. £200 p.a., with a credit of over £9000 in December 1819.

7.2 *Payments to assistants and draughtsmen*

These business records cover many of Telford's payments to engineers, surveyors and draughtsmen from 1819–1833. Although incomplete they give a good idea of how many people, he brought in to help him, and their various rates of pay. The accounts list the following (NLA Acc 19973):

Arrowsmith & Son (Engravers etc) 1824-29 (op. cit. F1-5);
Thomas Casebourne (surveying) 2 guineas a day; drawings etc. £1 10s) 1825-29 ca. £515 (op. cit. F6-26);
James Mills (surveying etc.) 1824-33 £1033 (op. cit. F30-44);
Henry Welch (surveying) 1828-36s a day £232 9s 10d (op. cit. F45-48);
Henry Robinson Palmer (surveying etc) 1819-31 10s 6d as an assistant, 1 guinea a day as engineering surveyor ca. £288 (op. cit. F 49-50;58);
Henry T Provis (surveying) 1825 £169 5s (op. cit. F51-53);
William Provis (surveying) 1827 £590 11s 5d (op. cit. F54-55);
Thomas Fletcher (surveying etc) 1827 £25 9s (op. cit. F56-57)
John Gibb (drawings and specifications) 1829 23 days @ 2 guineas £74 3s 11d (op. cit. F59, F 61);
Francis Hall (clerk of works) 1827 5 weeks @ £3 £15.00 (op. cit. F60)
William Cubitt (surveying) 1829 £48 (op. cit. F62)
William Smith (staff man) 1828 £22 (op. cit. F63)
Francis Dodd (1829-30) draughtsman/junior clerk paid 7s a day i.e., third of a guinea £29 14s 4d (op. cit. F64);
John Macneill (surveying) 1833 £2 2s a day £129 8s 9d (op. cit. F71)

Two examples are instructive. Palmer was Telford's chief assistant when he set up his office in Abingdon Street. From 1819-21 he was particularly involved with Burnham marshes. In August-October 1819 he spent 49 days at a guinea a day surveying the marshes, incurring £38 4s 2 in travelling expenses; in March 1820 he spent three days with Telford working on the report, again at a guinea a day. He then spent 25 days on preparing the maps, at the same rate, incurring a further £18 5s in expenses. He employed surveying assistants at 13s 8d, for £19 4s, and also purchased the materials to mount the map for £1 2s. For the project, Telford advanced him £110 in two instalments, and eventually paid him £157 12s 2d.

John Macneill was the overseer of the English section of the Holyhead road from 1826, but increasingly employed by Telford on a range of scientific and engineering matters. His surviving accounts for 1833 relate to the survey of the St Helps and Runcorn Gap railway for the Exchequer Bill Loan Commissioners (EBLC). Macneill's Bill was for £60 14s. Telford's bill was for £215 12s. Seaham harbour was another EBLC job. Macneill charged for six days' travel to Seaham harbour; five days at Seaham harbour measuring and seeking information, and 13 days in offices at Stowe and in London helping Telford in estimating for the completion of the works there – a total charge for Seaham harbour of 24 days at 2 guineas a day (£50) plus travelling expenses of £19 8s 9d. Telford can hardly have charged less than he had for the other job.

7.3 *The case of the Liverpool and Manchester railway*

Telford is well-known for issuing a critical report of the conduct of work on the Liverpool and Manchester Railway to the Exchequer Bill Loan Commission. He employed James Mills for gathering the data for the report. Mills was paid £341 2s for his work, made up of £26 12s 6d for travel expenses, including coach hire between London, Liverpool and Manchester, £220 10s 6d for surveying the works, including "tavern expenses" and £94 10s for compiling his report and associated plans (NLS Acc 19973 F44). Telford advanced him £250 for his work on various occasions. Telford billed for £629 (Thomas 54) suggesting he made modest charges for this work himself, quite reasonably given he only spent a day there in November 1828 and a few days in January 1829.

7.4 *Other expenditure: Telford's autobiography*

Telford is well-known as an author, not just of engineering reports, but he had made excellent use of his literary ability to promote his engineering ideas, notably with his proposal for a single 600 ft span cast iron bridge over the Thames around 1800. He was evidently prepared to invest his own money in high quality prints of the proposal. As noted above, he invested in, and wrote, for the Edinburgh Encyclopedia. Towards the end of his life, he began composing his autobiography (Rickman 1838: Preface). The bulk of the work for the accompanying was done by his clerk Turnbull, and engraved by Edmund Turrell at the fixed rate of 15 guineas for single plates and 30 guineas for double plates, having produced 66 around the time of Telford's death. Turrell had begun work in 1830, but Telford also employed Alexander Gordon, who had a lithography business at Paternoster Row (NLS Acc 19973 F66). His charges for producing three lithographic plates were ca. £26 – drawing and lettering the map of the British canals, and Llynn (sic) on (now Waterloo) Bridge £8 10s each; carving both 9s each; drawing the Portsmouth Dockyard Commissioners House £10.00, plus charges for stones at 6d a pound (lb): Llynfon £4 2s; Canals £3 13s and Portsmouth £1 7s 6d. Telford paid £29 for these and work on another of the Weaver in January 1831. This was then followed by further work, providing four proof copies, at 7s, printing 50 copies at 20s per 100, and hand colouring for 10s, together with the cost of paper, involving a payment of £13 12s in April 1831 (op. cit. F 69). At the same time, he purchased an ideograph from John Adie (op. cit. F67-68) for £16 16s, possibly to help Turnbull preparing the drawings for the lithographer. One begins to see how the costs of the Atlas of 83 plates rapidly mounted. It must have cost at least £1500 to produce, including Turnbull's contribution.

7.5 *Other expenses: Horse hire*

Telford is known to have owned his own post chaise but hired horses. He had an account paid annually with Robert Newman (1785–1863), postmaster of 121 Regent Street. for which bills survive 1825-33 (NLS Acc F141-145). Bills are of the order of £20–27 p.a., with costs varying from 16s for evening hire in London to £1 16s to Carshalton via Croydon. In 1825-26 he used the service 27 times, but in six months in 1833 17 times. Of course, this only represented a small part of his travelling expenses.

8 ENGINEERING SHAREHOLDERS

Surviving papers also provide some information on Telford the investor. Business ethics were very different in the 18th century than today, and having a financial interest in a scheme with which one was providing advice was not unusual. Telford is known to have acquired 25 shares in the Ellesmere Canal, probably over period of time (Wilson 1957). It was a scheme in which his long-time collaborator the mason/contractor John Simpson had 30 shares. The pair also had shares from its inception in the Glasgow Paisley and Ardrossan Canal, on which Simpson was also a contractor and Telford the engineer. Howell, who had also been surveyor on the Caledonian Canal was also a shareholder. Telford seems to have been the contact for the initial purchase for all three.

Later holdings were for the Macclesfield Canal on which Telford was consulted, and more substantially on the St Katharine Docks. On the latter, the chief promoter John Hall was clearly concerned about Telford's holding of two £1000 shares, and it was kept in the name of "Mr Milne" until the project was completed. (NLS Acc 19971 1825–1832: F67, F80, F83 F87, F88). To be able to meet the calls on such shares is indicative of Telford's surplus income at the time.

The notion of engineers investing in schemes with which they were professionally involved was not unusual. William Jessop took shares in the first scheme in which Telford collaborated with him – the Ellesmere Canal (1793) (Hadfield & Skempton 1979). Among his contemporaries, John Rennie had shares at his death in the Grand Junction Waterworks, East India Docks, and the Kennet and Avon, Grand Western, Rochdale, and Worcester and Birmingham canals, on all of which he advised (Cross-Rudkin 2020). Only the first two holdings were significant in value. Robert Stephenson is well known for his financial embarrassment from involvement with the Stanhope and Tyne Railway-not a limited liability company. I. K. Brunel was also well-known for investing in schemes with which he was engaged (Rolt 1957). They also formed for a time a significant source of his income, as he noted in his journal for 1836:

"One thing however is not right; all this mighty press [of work] brings me but little profit-I am not making money. I have made more by my Great Western shares than by all my professional work-voyons what is my stock in trade and what has it cost and what is it worth".

This investment strategy dated from the early days of the scheme when Brunel took 50 shares; although it was increased to 80 shares, on 27 October 1838 he could not meet the latest call, and G.H. Gibbs bought 50 of them, enabling him to pay the call on the remaining 30 (Simmons 1971). This determination to invest saw its unfortunate conclusion in the affairs of the Great Eastern steamship, which probably ate up a significant proportion of Brunel's accumulated wealth (Brunel 1870), leaving his fortune at death considerably less (£90,000) than his great contemporaries

Locke (£350,000) and Robert Stephenson (£400,000) (Chrimes 2019).

Such investments have been more typically associated with contractors, where they were offered shares in lieu of payment, or actively promoted schemes on the basis they could make money out of shares in due course. The diaries of William Mackenzie, one of Telford's resident engineers but later one of the most successful railway contractors, have numerous references to his share dealings (Brooke 2007) and the subject of contractors' lines has been relatively well-studied (Cross-Rudkin 2016) The well-known architect of the time William Tite probably made more money out of his railway investments than his professional fees, and his investments also paved the way for his professional employment as a railway architect and valuer (Chrimes 2021).

In another example of his entrepreneurship, in 1810 Telford reported to the Ellesmere Canal Co. on the need to provide graving dock and related facilities at facilities at Ellesmere Port, offering to take the lease on the land and sublet it, giving the Company the option to buy the lease back after 14 years for £5000; the Company contracted with him to do this in 1811 Brown).

9 TELFORD'S OFFICE AT 24 ABINGDON STREET

Telford's early peripatetic years were a reflection of a relentless ambition. He must have taken lodgings, but would not have had anything like an office until he worked in Portsmouth dockyard. This government project would probably have served as a good model for organization, and one can imagine he was well prepared when he began work at Shrewsbury Castle, where he probably kept or shared a room for many years to sustain his Salopian practice. He relied on his Scottish friends at first, and then trusted acquaintances and colleagues from Shropshire and elsewhere as his practice grew. From 1800 he had a presence in London, for many years at the Salopian Coffee House, Charing Cross, and also in Edinburgh. It appears his first pupil or assistant was William Provis, from c. 1808, and a paid assistant is mentioned in the accounts of the Highland Road Commissioners around that time. Before then one constant companion on trips to Scotland and elsewhere had been Hamilton Fulton who accompanied him to Sweden to study the Gotha Canal. At some time before 1820 he had mentored Matthew Davidson's three sons, although only James, the youngest, joined the profession. He also employed James Meadows Rendel as a young assistant from around 1817, possibly to replace Provis as his amanuensis. However, without a permanent office base he must have relied heavily on commercial draughtsmen and freelance surveyors to support his work, and relied on his various subordinates to draw up plans from his sketches and correspondence.

Telford's decision to take up premises at 24 Abingdon Street in 1821 was significant not only for Telford but the profession. He was probably the first engineer to take a permanent office in Westminster close to the centre of government. Previously consulting engineers tended to come to London for the parliamentary season but be otherwise based in the provinces where their clients were. Those in London were based around the city and in the industrial centres.

The Telford home became the model for the Westminster consulting office of the early railway age, with engineers living above the office and space for the consulting room and drawing office. Telford now had space to entertain his clients, and display his works of art of engineering works, including paintings of Menai and Bridge and Pont Cysysllte which he had commissioned from Arnold, as well as a Canaletto of Westminster Bridge. He had space for a drawing room for his assistants and organized accommodation for his papers so he could more effectively mentor pupils than had been possible before, as well as entertain his close friends over dinner.

He employed a servant, James Handscombe, for many years but his companions were generally young engineers. The first were sons of his friends – Joseph Mitchell and Alexander Gibb (Mitchell 1971). They were soon joined by George May. There were also regular assistants like Henry Robertson Palmer going out into the field and coming back to draw up their reports. When work began at St Katharine Docks from 1826, a number also spent time in the engineering office there, such as David Hogarth and Thomas Jeans. After May's departure in 1827 he offered William Gifford a pupillage. He resigned in late 1829 due to ill-health, which probably explains the employment of Francis Dodd as a junior draughtsman at that time. In March 1830, George Turnbull joined Telford at Abingdon Street as a clerk and draughtsman on a salary of £80 p.a. plus board and lodging, having previously been on the staff in Thomas Rhodes' office at St Katharine Docks (Turnbull 1893). Turnbull was Telford's last such junior assistant, remaining with him until his death. The other regular attendees at the time being Charles Atherton, Thomas Casebourne, John Macneill and James Mills.

It is believed the rent was £180 p.a. paid quarterly, the landlord being Anne and John Stables. (NLS Acc 19973 F146-180 1822–1834). This is consistent with an income of c £1400 p.a. at the time. (Banks 1954).

10 TELFORD IN 1833

By 1833 Telford was an elderly man, suffering at least 14 days of sickness. The scale of his work in hand undoubtedly reduced considerably, and he only had one assistant, Turnbull, sharing his home. However, there was something like £160,000 work being conducted with him as engineer, notably the Birmingham and Liverpool Junction Canal and work in the Fens. His diary survives (NLS Acc 9157), and if one excludes income from investments his known billed fees for the projects on which he was working in that year amounted to £6361, while given the time he spent on other projects – 58 days – he might have been expected to bill for at least £400 for his own time, plus that of his assistants. These sums may seem astounding, but he spent more than 50 days on the Metropolis Water Supply inquiry (fees £5000), employing, beyond Casebourne, Macneill, Mills and Turnbull, senior engineers like Bryan Donkin and William Cubitt.

11 CONCLUSIONS

Smiles is correct in his assessment that Telford's income and wealth was dwarfed by the leading engineers of the railway age; however, his total income in excess of £2000 p.a. as represented by investments and consultancy fees through the 1820s would have put him on par with successful business people and the wealthier gentry, as seen in Table 1. Such a view is not incredible given that he left over £34,000, and had only begun earning at a serious level in the late 1790s, giving a surplus income of over £1000 p.a. being saved over a sustained period.

While his fees to public clients of £5 5s were not excessive, he was also charging 7 guineas to private clients. His fees were the norm for the time, and set the foundation for the fees of the railway age. He employed a number of assistants at different rates of pay to support his consultancy work, some of whom were salaried assistants on other projects. His wealth at death would have provided sufficient income to live off comfortably without the need for further labour. It enabled him to indulge his generosity to friends, and invest in an ambitious autobiography produced to a standard which was never to be emulated by his wealthier successors in the profession. Meanwhile, taking out a lease at 24 Abingdon Street Westminster was not only a significant step in Telford's own life, but it also represented a new phase in the consulting engineering profession, with leading engineers for the first time taking up permanent offices close to Parliament and the government offices in Westminster. Telford had emerged from obscurity financially, professionally and politically, and the great Victorian engineers were soon to follow.

A Note on UK currency. Prior to decimalization in 1971 a UK pound sterling (£) comprised 240 pence (d), more commonly divided into 20 shillings (s) of 12 pence (d). The crude conversion rate in 1971 gave the following values: 1p (new pence): 2.4d (old pence); 5p: 12d: 1s (shilling). Historically a guinea i.e. 21 shillings or £1 1s was frequently used for fees and other costs.

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History of Construction Cultures – Mascarenhas-Mateus & Paula Pires (eds)

Modernization of civil construction in Brazil in the second half of the 19th century: Strategies of a local entrepreneur

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ABSTRACT: This article contributes to understanding the modernization processes of the civil construction industry in Brazil in the second half of the 19th century. It analyzes the role played by Antônio Carlos Sampaio Peixoto, an entrepreneur in the city of Campinas-SP who owned a factory inaugurated in 1867 that manufactured bricks, tubular pieces, and tiles. The factory was composed of a foundry (iron and bronze) and a blacksmith shop, which produced materials (railings and fittings) essential to civil construction modernization. The entrepreneur's actions were broad, not limited to the modernization of his industry, but expanding to include political and social action. As a strategy to amplify its sales and diffuse its products, Sampaio Peixoto advertised in local and regional newspapers. This research is based on the analysis of articles published in these newspapers and photographs that register the installations and production processes of Imperial "*Olaria Ferraria*" and "*Oficina Mecânica*".

Keywords: Translated with www.DeepL.com/Translator (free version)

1 INTRODUCTION

This article aims to analyze Brazil's construction industry's modernization process in the second half of the 19th century. To do so, the research uses the case study of a local actor and contextualizes his actions within the Brazilian and international settings. Antônio Carlos Sampaio Peixoto (1835–1914) was a businessman in the city of Campinas, Brazil. In 1867, he inaugurated a mechanized brick factory that used steam-machines imported from the United Kingdom. In 1868, Sampaio Peixoto expanded his company by inaugurating a mechanical workshop, a smithy, and an iron and bronze foundry. In 1875, he received authorization to use the imperial coat of arms on his products. Sampaio Peixoto's actions went beyond the management of his industry. They are connected to a broader project aimed at the modernization of Campinas city in the second half of the 19th century. This research analyzes Sampaio Peixoto's role on the committee of the city's most relevant public construction project – the church *Igreja Matriz Nova*. It also analyzes his role in the debates surrounding the use of brick masonry as a construction technique for buildings in Campinas. The social and political relationships formed by Sampaio Peixoto were essential for the advancement of his project of modernization.

To expand the sales of his industry's products, Sampaio Peixoto frequently placed advertisements in the local press, as seen in Figure 1. Further research into these newspapers also showed a broader movement meant to present new industrialized products and new construction techniques as indications of progress.

GAZET

TIJOLOS

Grande abatimento e a dinheiro

O abaixo assignado declara aos seus freguezes, que de 1 de Fevereiro em diante, venderá tijólos pelos preços seguintes:

Tijólos de construcção 10 1/2 por 5 polegadas de largura e 3 ditas de grossura a	35$000
Ditos de dita « « de dita e 3 de dita imprensados a	40$000
Ditos de dita 9 1/2 por 4 3/4 ditas de dita e 3 de grossura	[illegible]0$000
Ditos de ladrilho 9 por 9 pollegadas em quadro e 2 de dita	60$000
Ditos de dito « « « « e 2 de dita imprensados	70$000
Ditos para moldura (imprensades)	60$000
Ditos para poço (ditos)	60$000
Tubos para encanamentos	80$000

N. B. Esta medida é ingleza.

Quando a encommenda exceder de 10 milheiros haverá grande abatimento dos preços acima em relação ao n. de milheiros; os preços acima são de tijólos entregues nas obras dentro desta cidade, e quem quizer conduzil-os por sua conta terá mais o abatimento de 5$ em cada milheiro. Encommendas por escripto á rua da Constituição n. 11 ao abaixo assignado, ou na olaria ao sr. Luiz Bichof.

5—1

A. C. Sampaio Peixoto.

Figure 1. Announcement for the sale of bricks produced at Olaria de Antônio Carlos Sampaio Peixoto published in *Jornal Gazeta de Campinas* on 31 February 1878. Source: CMU, Gazeta de Campinas, 1878. Accessed 26 November 2020.

The materials used in this investigation were primarily primary data extracted from newspapers (*Gazeta de Campinas* – a daily circulation newspaper in Campinas; *O Estado de São Paulo* – a newspaper from the city of São Paulo, the capital of the Province of São Paulo, which contains plenty of material about Campinas), building law almanacs and *Códigos de*

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Posturas (produced annually in Campinas), especially from 1880.

The almanac was a trendy type of publication in Campinas in the 1870s and 1880s. Almanacs contained statistical information about the city, such as data on railroads, free and immigrant workers, factories, schools, and education. Many announcements of factories, commerce, and liberal professionals were also carried in almanacs (Galzerani 1998).

2 MODERNIZATION OF THE CONSTRUCTION INDUSTRY IN THE CITY OF CAMPINAS, SP

In Brazil, the diversity of construction techniques used from early colonization was conditioned by the availability of materials and skilled labor. In Campinas and the entire region of São Paulo's highlands, the rammed earth technique (*taipa de pilão*) was used in early construction because no stones or limestone could suggest a different type of masonry, such as brick masonry. Even with its limitations, the rammed earth technique began to characterize the region's architecture (Lemos 1989).

The transition between the colonial economy and the capitalist export economy brought essential innovations to construction in the Province of São Paulo. The new society, born from large-scale coffee production, began to demand construction elements that were not yet available in the market. New means of production were developed to meet the growth of the urban nucleus connected with coffee production regions. Other than construction material imports, local industries began to develop, looking to import machinery to meet the rising internal market's needs.

Baked clay bricks were an unknown material in the region. There are a few records on the use of the rammed earth technique (*taipa de pilão*) in some public construction projects, but its production was small scale and artisanal, with irregularly shaped parts and low resistance.

In the second half of the 19th century, large-scale coffee plantations popularized brick masonry, especially in buildings tied to the production process. Bricks allowed for efficient construction of aqueducts, tanks to wash coffee beans, brick masonry, and paving of the terraces for drying the beans. The arrival of the European workforce to work on the coffee plantations also contributed to the diffusion of brick masonry as the region's primary construction technique, as many workers knew the material. As demand for the material continued to grow, brick factories opened near clay deposits. "In January of 1860, the newspaper *O Agricultor Paulista* announced that London already had machines that produced 20 to 25 bricks per day, drastically cheapening the production of bricks […]" (Lemos 1989, 41).

In Campinas, the development of the construction industry structured itself through the growing demands of construction within the city, not those of coffee plantations. Surplus capital from the plantations was employed in the urbanization and modernization of the city.

3 SAMPAIO PEIXOTO: A MAN OF MANY TALENTS

Antônio Carlos Sampaio Peixoto (1835–1914) was the son of Maria do Carmo Silva Leite and Antônio Joaquim de Sampaio Peixoto, a landowner, lawyer, and representative of Campinas as a provincial congressman. After finishing middle school in Campinas, Sampaio Peixoto was sent to the capital of the province, São Paulo, to finish learning Latin, French, and English. Although his parents wanted their son to study law, Sampaio Peixoto never finished his studies, for his true vocations were fine arts and mechanics (Amaral 1914). An article in the newspaper *O Estado de São Paulo*, published in 1965 as a tribute to the life and memory of Sampaio Peixoto, points out that he always stood out "for the elegance of his good manners and the rigor of his dressing: he was a perfect gentleman who knew how to discuss a variety of subjects for his varied erudition gave him that privilege" (*O Estado de São Paulo* 1965, 29). His vocation for the arts became evident in the accounts that described his regional exhibitions of watercolors and other paintings. He also actively cooperated in constructing the organ installed next to the choir of the church *Matriz Nova de Campinas*. As someone who was skilled and had an affinity for music, Sampaio Peixoto studied the instrument's operating mechanics and was an organist at the church between 1885 and 1887 (Brito 1958). Through matrimony, Sampaio Peixoto joined one of the most important landowning families of Campinas, the Souza Aranha. After his marriage he withdrew, until 1861, to Joaquim Egídio de Souza Aranha's farm, his father-in-law and Marquis of Três Rios. Sampaio Peixoto did this to develop and improve his skills tied to agriculture. This was probably the source of his interest in developing, working, and producing agricultural machinery, especially connected to coffee production.

Sampaio Peixoto's first important role in construction in Campinas was in 1862 when City Hall nominated him to administer the church *Matriz Nova*'s construction, a role previously occupied by his father. According to Amaral, Sampaio Peixoto had a crucial role in hiring new woodcarvers in the Court, which provided a new plan for the church's construction (Amaral 1914): two chapels, two corner altars, and four side altars were executed within three years. The administrator's position allowed him to impose his aesthetic decisions on the construction of the *Matriz Nova* (Rodrigues 2010).

The construction of *Matriz Nova* began in 1807 and ended only in 1883. When Sampaio Peixoto took on the administrator's role, the church's entire body was already robust, built of walls of rammed earth, the construction technique most frequently used in the Campinas region. However, there were structural problems in parts of the foundation, and the design of the frontispiece had not been defined (Barrantes 2014). The slowness of the solutions to these problems was mainly due to the rammed-earth construction's exposure to the weather: the lack of tile eaves led to the constant wear of the structure and occasional seepage and cracks (Brito 1958).

To circumvent these issues and finish the church's construction, Sampaio Peixoto traveled to Rio de Janeiro to search for skilled professionals (architects, engineers, and licensed practitioners). These trips also revealed Sampaio Peixoto's efforts to know and understand the Court's architecture by contacting the professionals who produced the most modern constructions in Brazil at the time.

The search for a modern solution for the *Matriz Nova* façade was tied to the idea of progress and renovation of taste, shared by Campinas' economic elite. However, the architecture produced in the capital and the structural solutions to construction were heavily influenced by the use of stonework and stones, which was abundant in the region of Rio de Janeiro.

Francisco Bethencourt da Silva, the Imperial Academy of Fine Arts architect hired by Sampaio Peixoto, did not design his building in rammed earth. The design he originally proposed for the frontispiece of the church *Matriz Nova* of Campinas, which contained two towers, was conditioned to his construction technique using stone masonry. However, this solution was too difficult to implement in Campinas because the stones extracted from the region were scarce and irregularly shaped, which created problems in sizing and standardization (Barrantes 2014). Furthermore, there was no skilled manual labor who could work with this material in the city.

Thus, Bethencourt's design was altered to contain a single rammed earth tower. Moreover, because of these attempts and mistakes, including disasters, he began implementing the lessons learned from the Imperial Academy of Fine Arts in São Paulo's countryside, mixed with regional materials and techniques (Rodrigues 2010). These conditions led to revision of the plan of the façade. This decision is attributed to the engineer Charles Romieu, who, after studying the terrain, decided to erect only one tower where the chorus would have been. It was built of four stone columns, lime, and bricks: two in the interior and two in the exterior of the church (Rodrigues 2010).

In November 1865, the stone that was fundamental to the new façade's construction was launched. Two months after the inauguration, on 11 January 1866, the foundation's excavations collapsed and took down surrounding equipment, which buried five workers (Barrantes 2014).

On 30 January 1866, Sampaio Peixoto resorted to the press to issue a public apology and published in the newspaper *Gazeta de São Paulo* an extensive article with the title "The Disaster of the *Matriz Nova*" in which he discussed, in detail, the accident and the hardships faced during his administration of the construction. He described his constant search for technical knowledge to refine the construction and talked about a consultation "[…] with the engineers, in an expedition to the province of *Mato Grosso,* who passed by Campinas to thoroughly examine the edifice and offered a few plans for the facade […]" (Peixoto 1866).

In 1867, Sampaio Peixoto was found not guilty of being responsible for the accident. The investigation concluded that heavy rains that flooded the terrain were responsible for the collapse (Barrantes 2014). The accident in the construction of the *Matriz Nova* of Campinas was a turning point that intensified the debates about the need to substitute the rammed earth technique as the primary construction method used in the city. Adopting the new aesthetic from the Court, tied to the fondness for neoclassical architecture, would only be viable by substituting materials and construction techniques. "The creation of the brick factory and the systematic and mechanized production of bricks by Sampaio Peixoto could have been a reaction to the diverse accusations against him that naturally came in the years after the incident of 1866" (Rodrigues 2010, 194).

The decisive initiative for substituting the traditional rammed earth technique for bricks seems to have been motivated mainly by the *Matriz Nova* de Campinas façade's collapse. However, the desire for change had already been expressed by local farmers who, since 1860, used artisanal bricks in constructions tied to the processing of coffee: brick masonry, the pavement of the terraces for drying coffee beans, and aqueducts.

4 THE IMPERIAL BRICK FACTORY

On 2 December 1867, Antônio Carlos de Sampaio Peixoto inaugurated his mechanized brick factory, which produced bricks, tubular pieces, and tiles using steam-machines imported from the United Kingdom. In 1873, there were 12 other brick factories in Campinas, showing the construction industry's dynamism at the time. However, only Sampaio Peixoto's brick factory had an entirely mechanized production line in tune with the most modern international production. Along with the brick factory, Sampaio Peixoto also owned a bronze and iron foundry and a smithy capable of producing large materials such as grids and hardware. These materials were essential to the modernization of local and regional construction.

In 1875, Emperor Dom Pedro II visited the brick factory. He was impressed by the products' quality and authorized using the imperial coat of arms on the products (Pupo 1969). From then on, the factory was renamed *Imperial Olaria Ferraria e Oficina Mecânica Sampaio Peixoto* – Imperial Brick Factory, Foundry, and Mechanical Workshop Sampaio Peixoto. Figures 2–4 present some of the company's products with the imperial coat of arms.

Figure 2. Brick produced at Sampaio Peixoto’s Imperial Brick Factory. The name of the company and the imperial coat of arms are stamped on the brick. Dimensions: 26.2 cm × 7.3 cm × 12.9 cm. Source: Dutra auctions. Available at: http://www.dutraleiloes.com.br/2018/l139/catalogo2.asp. Accessed 26 November 2020.

Figure 3. Tile produced at Sampaio Peixoto’s Imperial Brick Factory. The name of the company and the imperial coat of arms are stamped on the center of the tile. Source: Began and Marise Domingues, antiquities and auctions. Available at: https://www.marisedomingues.com.br/peca.asp?ID=4225227. Accessed 26 November 2020.

Figure 4. Brick produced at Sampaio Peixoto’s Imperial Brick Factory. Product has a particular shape to be used for the construction of arches. The name of the company and the imperial coat of arms are stamped on the brick. Source: Miguel Sales auction and Art Space. Available at https://www.miguelsalles.com.br/peca.asp?ID=5168169. Accessed 26 November 2020.

5 ADVERTISING THE COMPANY AND ITS PRODUCTS IN THE LOCAL PRESS.

This research verified that in the local press, in the 1870s, many articles defended the use of brick masonry as a construction technique capable of promoting the embellishment and the modernization of constructions. J.A.A. Van Halle, a traveler and columnist from the newspaper *Gazeta de Campinas*, criticizes the use of the rammed earth technique in his article “*Progressus – Industria – Veritas*” where he talked about his trips to the cities of the Province of São Paulo: “I repeat, still, that the buildings constructed with rammed-earth technique cannot be grouped with other monuments, despite the richness of their ornaments. This is because they are stripped of all the rules of architecture and the rules of stonework sculptures. They are only embellished with ornaments made of plaster, and their fragile nature prevents them from resisting torrid temperatures and torrential rains that are so frequent. For these reasons, buildings made of rammed earth technique do not deserve the honor of being classified or mentioned in the art history of a country” (Van Halle 1872).

One of the strategies used by Sampaio Peixoto to increase sales and encourage the use of his factory’s products was to publish advertisements in local and regional newspapers. This research is based on analyzing these advertisements and articles that described the Imperial Brick Factory, Smithy and Mechanical Workshop, its machines, and its production process.

The advertisements showcase many of the company’s products and services. In the 1870 issue of the newspaper *Gazeta de Campinas*, there is an advertisement about the arrival of machines from the United Kingdom for processing coffee. To meet the needs of agricultural producers from Campinas and its surrounding regions, the following devices were also produced by the company: sugar cane mills, centrifuges

Figure 5. General view of the Sampaio Peixoto Imperial Brick Factory and Smithy where one can see the house containing the hydraulic wheel. Date: 1869. Collection from the Brazilian National Library. Available at: http://acervo.bndigital.bn.br/sophia/index.asp?codigo_sophia=42175. Accessed 26 November 2020.

used in the production of sugar, machines to pump up water, fans that killed ants, steel mills to grind corn, and circular and vertical saws. To meet the construction market demands, the company sold simple presses and bending machines to produce bricks and tiles. There are also advertisements in the newspapers that ask suppliers to deliver firewood to bake bricks (*Gazeta de Campinas* 1873, 3).

On 3 April 1870, Francisco Quirino dos Santos, the editor of the newspaper *Gazeta de Campinas*, published an article in which he recounted his visit to the Imperial Brick Factory, Smithy and Mechanical Workshop. A reconstruction of the factory's operation was made possible by analyzing this newspaper article (Santos 1870, 1–2) and photographs from 1869 (Figures 5, 10).

Campinas was already considered an important center of agricultural production and trade, and the article praises the progress that came to the city through the inauguration of new factories. The steam machines and the three chimneys installed at the factory were seen as indicators of the city's progress.

The factory was located on a "*chácara*" near the eastern suburb of the urban center, as shown in Figure 5. In Brazil, the "*chácaras*" are properties located between the urban nucleus and the rural space. In the 19th century, the elite built manor houses in the "chácaras", but it was also common for these properties to produce fruit and vegetables for consumption in the city. In the second half of the 19th century, the first factories in Campinas were located in "*chácaras*".

The land was located next to a watercourse where clay for brick production was extracted. The brick factory occupied an area of 27,500 square palms. The hand's length – originally the Roman "greater palm" – formed the palm of medieval Italy and France. The customary unit of a palm ("*palmo*" or "*palmo de craveira*") was the span between an outstretched thumb and little finger in Spanish and Portuguese. One palm is about 22.86 cm. In the 19th century in Brazil, this measure was widely used before the mandatory adoption of the metric system.

Figure 6. Part of the brick factory from where the bricks were transported to the furnace. Date: 1869. Collection from the Brazilian National Library. Available at: http://acervo.bndigital.bn.br/sophia/index.asp?codigo_sophia=42170. Accessed 26 November 2020.

There were two buildings to dry up to 160 thousand bricks. One of the houses was 60 palms long and 40 palms wide; the other was 320 palms long and 60 palms wide. The larger house contained seven shelves and four hallways with steel tracks that ran from the machines to the first drying house and passed in front of the three furnaces placed between the houses. The furnaces baked 70 thousand bricks at a time. Four thousand one hundred ninety-two palms of tracks that transported nine wagons branched out from the entire brick factory, as shown in Figure 6.

The machine that produced bricks was located in the second drying house and was part of the Clayton and C. n BB. System. It produced 1500 bricks per hour with a variety of presses that allowed it to delicately and neatly perfect the shape of the bricks. Figure 7 demonstrates how the clay arrived at its respective deposit on a wagon that ran on tracks on an inclined plane. A regulator signaled when there was too much or too little water in the machines through a bell. Another record regulated the amount of water for the hydraulic wheel that had 1–8 horsepower.

A large water canal ran through the brick factory and arrived at a tank made of bricks and hydraulic cement, as shown in Figure 8. The canal was divided into two smaller streams: one led to the water wheel that powered the machines, and the other to the corn mill. The wheel had a diameter of 20 palms and a thickness of four palms. A high-pressure pump placed on the canal next to the inclined plane soaked the clay in three large tanks.

Figure 7. Inclined plane on which the steam wagon that transported clay to the machines functioned. Date: 1869. Collection from the Brazilian National Library. Available at: http://acervo.bndigital.bn.br/sophia/index.asp?codigo_sophia=42171. Accessed 26 November 2020.

Figure 8. Houses where bricks were dried, water canal and pressure pump to wet bricks. Date: 1869. Collection from the Brazilian National Library. Available at: http://acervo.bndigital.bn.br/sophia/index.asp?codigo_sophia=42172. Accessed 26 November 2020.

Figure 9. Building with forges powered by steam and water. Date: 1869. Collection from the Brazilian National Library. Available at: http://acervo.bndigital.bn.br/sophia/index.asp?codigo_sophia=42173. Accessed 26 November 2020.

Inaugurated in 1867, the brick factory had produced, up until the article's publication date, around one million bricks of different varieties: solid bricks for construction, three types of tubular bricks, and tiles and tubes for plumbing. Twenty-nine people worked on this part of the factory, but the article does not clarify the percentage of salaried workers and slaves (Santos 1870, 1).

The grounds in which the smithy and mechanical workshop (Figure 9) were located were 6900 square palms large. It had five forges, four of which were powered by steam or water and one of which was powered by a larger forge below. The building that contained the smithy and the mechanical workshops, which were 2400 square palms large, was spacious and airy. Each forge had tools and huge anvils. There were two large bench vises in the center of the building, and right beside them, there were two storages: one that contained cast iron, and the other which contained wrought iron.

The mechanical workshop was in a room that was 100 palms long and 25 palms wide, with five windows and many skylights. There was also a large bench with five vises and a fixed five-cylinder engine with 10 horsepower by the Clayton Shuttleworth Lincoln system in the room. There was a water heater at the motor base, with a tap to fill it and a circular saw that cut the firewood it needed. The workshop also contained machines to screw screws, pierce and trim materials, a planer, an iron fan to melt metal, and five forges.

The mechanical workshop and the second brick dryer were located under the same roof and were

Figure 10. Machine that pierces materials, bench and foundry. Date: 1869. Collection from the Brazilian National Library. Available at: http://acervo.bndigital.bn.br/sophia/index.asp?codigo_sophia=42176. Accessed 26 November 2020.

different parts of an interconnected whole. Between the workshop and the dryer there was a 130-palm transmission space from which started on one side three belts: one for the brick-making machine, another for the wagon to transport clay, and another to give impulse to these machines' regulator. There were belts to move the circular saw to the planer, to the drilling machines and the fan for other directions. The same transmission received a large belt from the steam wheel and another from the hydraulic wheel. The workshop was inaugurated in 1868 and had 22 professionals described as very skilled.

Sampaio Peixoto's office was an elegant little room with openings strategically placed to supervise different parts of production. Ropes and bells coming from different parts of the factory were used for communication. In the article, the newspaper editor claimed that the factory's artifacts' excellent quality was comparable to that of imported products. Many places in the Province of São Paulo and some in the neighboring Province of Minas Gerais placed orders as well. It was common for Sampaio Peixoto to receive letters from clients satisfied with the products' quality (Santos 1870, 2).

6 LEGISLATION AND THE MODERNIZATION OF CONSTRUCTION IN CAMPINAS

Francisco (2013) considers the Municipal Codes (*Códigos de Postura*) an essential source to understand the incorporation of bricks as the most used construction technique in Campinas. The Municipal Codes were a collection of behaviors directed at the inhabitants of cities in Brazil in the second half of the 19th century. Campinas had five Municipal Codes, published in 1829, 1858, 1864, 1866, and 1880. These codes were formulated when the city underwent transformation and required legislative instruments that regulated urban space use (Lapa 1995). We analyzed the code of 1880 since that was where we identified articles that reflected a modernization project for the city, particularly in the first section about "Building and Embellishment", which took care of the aesthetic and technical aspects of construction. Article 8 also reveals this thought: "The houses that will be built from now on in the city can be done so according to the taste and the architecture of modern constructions. […] the main walls or pillars that sustain houses or buildings must be made with precise solidity to guarantee the construction's complete safety. The inspector is responsible for ensuring this and for calling experts to share their opinion in case of doubts" (*Código de Posturas de Campinas* 1880). Although the code does not require the mandatory use of brick masonry, many construction professionals considered that the solidity necessary to guarantee the construction's safety could be achieved by incorporating this modern technique.

In practice, what can be observed in Campinas is that the incorporation and diffusion of brick masonry as a new way of building was not sudden. The mandatory use of brick would only be incorporated into legislation towards the end of the century, in 1894, with the enactment of the Sanitary Code of the State of São Paulo (within the context of the government's republican regime). This code was based on sanitary engineering principles, with a focus on the spatial reorganization of cities. Its content was divided into 27 articles that considered civility and hygiene as synonymous with modernity and embellishment. Chapter II dealt with "dwellings in general", and in it, article 38 demanded that: "In the construction of dwellings, solid, resistant, dry materials should be employed that are refractory to moisture and that are poor conductors of heat." The Sanitary Code application in Campinas coincided with a moment of economic development and the recurrent epidemic outbreaks of yellow fever that forced the restructuring of the urban space and the incorporation of hygienic measures in the buildings. Although, not as significant with what was happening in the city of São Paulo, Campinas became a laboratory of architectural and constructive experiences (Francisco 2013, 98). The architecture produced in this period reveals buildings designed by renowned engineers and architects, many who trained abroad, and immigrant builders who already had the technical mastery of brick masonry from their practice on the construction sites.

7 FINAL CONSIDERATIONS

The buildings of the Imperial Brick Factory, Smithy and Mechanical Workshop no longer exist. After the factory's operation was concluded, the machines were sold, and there is no information about what was done with them. The original location of the brick factory has been completely altered due to the process of urban expansion. Currently, it is still possible to find bricks produced by Sampaio Peixoto in antiquity auctions. Therefore, in the absence of traces of materials, the reconstitution of the factory's facilities was based on reports published in the newspaper *Gazeta do Povo* in 1870 (Santos 1870, 1–2) and based on photographs of 1869 from the collection of the National Library (Figure 5–10). The research shows that the local press was an essential ally to Sampaio Peixoto in promoting the quality of the materials he produced. The factory was considered a symbol of technical progress and a key player in the modernization of local construction. Based on the analysis of a local actor's actions, the research shows how influential networks were that affected the modernization of Brazil's construction industry.

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History of Construction Cultures – Mascarenhas-Mateus & Paula Pires (eds)

Brussels iron and steel builders in the 19th and 20th centuries: A macroeconomic and spatial exploration

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ABSTRACT: In construction history research, the focus is often on large and prominent enterprises, whilst small and medium-sized enterprises (SMEs) remain largely overlooked. Yet, in Brussels, like in other major cities like London, 67% of construction workers were employed in SMEs in 1896 – a number that remained relatively constant until today. Accordingly, these historically long-neglected members of the urban construction industry were largely responsible for meeting the growing demand for building and ongoing maintenance during the city’s expansion during the 19th and 20th centuries. SMEs can, therefore, be considered as equally crucial and persistent players in urban construction economies. This paper seeks to sketch a broader framework of the Brussels’ construction industry during the past two centuries, including both SMEs and larger enterprises. We particularly focus on iron and steel builders, including merchants, foundries, forges and steel joiners, yet also draw comparisons with another subsector, namely joiners and carpenters.

1 INTRODUCTION

The Belgian construction industry is traditionally marked by SMEs (small and medium-sized enterprises) (Degraeve 2019; Hillebrandt 2000; Sage 2013). Nonetheless, scientific literature generally focuses on large-scale, iconic companies (Culot et al. 2018; Godoli et al. 2012), leaving most of the industry unstudied (Dobbels 2019). Despite some interesting case studies on smaller enterprises (Wouters & Wibaut 2019), this hiatus renders the historical practices of the entire industry insufficiently studied.

In this paper, we set out to sketch a more complete picture of the construction industry, by including SMEs. We particularly focus on the steel and iron construction industry. In the first part, we seek to understand the macro-economic trends of metal processing activities by looking into their evolutions in multitude and magnitude (employment) between 1833 and 1965.

Secondly, the paper sets out to assess the agency of space. For each type of enterprise, from merchants, large-scale foundries and artisanal forges to joineries, geographical mapping analyses are performed on the city level to sketch steel and iron builders’ location strategies. These settlement patterns are, thereafter, combined and related to the spatial organisation and infrastructural needs of the production processes.

Throughout the text, comparisons are made with the timber sector (Degraeve et al. 2018), thus making it possible to grasp the specific and representative character of the urban iron and steel industry, whilst further refining the applied methodologies.

The paper fits within the framework of the interdisciplinary research project, Building Brussels, which seeks to understand the building industry by looking explicitly, yet not exclusively, into SMEs (Degraeve et al. 2018). We focus on the patrimony that the construction sector built for itself during the 19th and 20th centuries. In analogy to emerging studies on architects’ houses (Raaffels et al. 2020), the workshops, houses and structures of builders can be regarded as sediment of local skills and expertise, embedded within the particular socio-economic and cultural context. The spatial strategies of the construction sector, both at the level of the city and the building, remain hitherto largely unstudied, yet they can be deployed as a source to gain a better understanding of the construction sector. By investigating both the geographical distribution and the typological setup of these buildings, we aim to discern recurring spatial arrangements, related to specific construction activities.

2 ECONOMIES OF SCALES AND CRAFTSMANSHIP

To compose a structural overview of the iron and steel sector in Brussels, three serial historical sources were used. First, the trade directories or *almanachs*

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Table 1. Evolution of enterprises, employees and firm sizes in iron and steel trades in Brussels (Degraeve, in prep.)

	1831/33	1846	1864/66	1896	1899	1910	1932	1937	1965
# enterprises	184		424	695	742	653	681	231	393
employment (incl. entrepreneurs)	378	795		2859		2955		1985	
average firm size (incl. entrepreneurs)	2.6		3.0	4.1		4.5		8.6	
# enterprises per 10,000 inhabitants	17.2		14.2	13.2	13.4	10.0	7.8	2.6	3.8
employment per 10,000 inhabitants	35.3	42.3		54.2		45.3		22.3	

du commerce et de l'industrie, provide yearly updates of active enterprises, listed per trade (Brussels City Archives 2016, online). Secondly, the 19th-century fiscal *registres des patentables* (BCA) list the Belgian entrepreneurs that paid the obligatory 'patent tax' to execute their trade. These registers include employment numbers since taxation was based on the number of labourers, yet these data are incomplete and discontinuous. Therefore, the censuses of commerce and industry are used as the third main source. They list the number of enterprises per trade, as well as employment figures, on an aggregated municipal level. Taken together, these sources make it possible to provide a long-term insight into the macro evolutions of the iron and steel construction sector in 19th- and 20th-century Brussels.

Based on key events in the history of the building sector, such as cyclical upturns and depressions, and the availability and accuracy of the sources, we selected nine benchmark years. We examined and processed the data for each of these years, and filtered out those pertaining to all builders, producers and merchants in iron and steel, which resulted in Table 1. In addition to the absolute number of enterprises, total employment rates and average firm sizes (including the entrepreneurs), figures on 10,000 inhabitants are included to assess their evolving importance in relation to the urban expansion and population growth. Because each source had its advantages and disadvantages, for instance in using different definitions and methods to register iron and steel enterprises, some figures were omitted in Table 1 (Bertels 2008: 4; Buyst 1992: 136; Debroux 2012: 105–7; Degraeve in prep. Hannes 1975; Lemmens 1988).

What immediately becomes apparent from Table 1 is the sheer magnitude of the sector, with hundreds of enterprises and, at their peak, thousands of labourers, in a city that expanded roughly tenfold to around 1 million inhabitants in this period. Besides that, two main observations come to the fore.

First, Table 1 shows that the urban market for iron and steel was expanding in the 19th century. Growing numbers of firms and labourers were involved in the sector, and most importantly, relative employment figures were on the rise. Simultaneously, however, the relative number of enterprises witnessed a long-term decline, which continued into the 20th century, to reach an all-time low at the height of the 1930s crisis. These seemingly opposite trends bear witness to a shift towards an increased scale of production and market concentration, where growing numbers of labourers were centralised within fewer production units of large-scale foundries and *ateliers de construction* (Marneffe 2020, Wouters & Wibaut in prep.), due to the competitive advantages they obtained from economies of scale and the mechanisation of production (Bennett et al. 2019; Hannah 1976). The 20th century was characterised by generally declining numbers that point in the direction of a shrinking urban market. In combination with lower demand in the 1930s and increased productivity, this decline was caused by the interaction between the upscaling and relocation of iron and steel production outside the densely built city.

Second, while firm sizes indicate a trend of long-term growth, the average firm size never exceeded ten employees. The majority of the iron and steel enterprises continued to work on a very small scale, despite the ascent of economies of scale. In the early 19th century, the dominance of small-scale craftsmanship of blacksmiths and lock and stove smiths was still evident. The latter were often merged in Belgian cities and executed all sorts of small, often unmechanised ironwork (Marneffe 2020: 92). But even as industrialisation progressed, a new appreciation of elaborately decorated wrought iron gave rise to many new specialisations (Hennaut & Demanet 1997: 22–23). In the 20th century, small iron and steel firms persisted, for instance by reorienting towards local and individual needs for renovation and assembly. More than the rigidity of mass production, their small scale and specialised skills enabled a flexible position in the market, where their specialised skills allowed for swift responses to the rapid shifts in market demands that characterised the construction sector as a whole (Harris & Buzzelli 2005).

The iron and steel sector thus moved forward as a highly representative building trade. The mechanisms of market concentration and persistent fragmentation can similarly be perceived in other trades, such as the timber subsector. Joiners, carpenters, timber traders and sawmills equally made up a vast part of the urban construction market that was characterised by a long-term decline due to mechanisation and economies of scale, the impact of which nevertheless became clear a few decades later than for iron and steel (Degraeve, in prep.). In both sectors, however, most enterprises that stayed in the city were invariably organised on a strikingly small scale. The question remains how the (mostly small-scale) iron and steel workshops were spatially organised within the densely built urban fabric, and how this compares to the spatial patterns of the timber industry (Degraeve et al. 2018; Vandyck & Degraeve 2019).

3 SPATIAL PATTERNS

In the following section, we examine whether, and how, this dichotomy in the organisation of Brussels iron and steel construction companies, with economies of scale on the one hand and craftsmanship on the other, manifested spatially. Based on detailed analyses at two related levels of scale, i.e. that of the city region and that of the corporate premises along with their use, recurrent settlement patterns are outlined to understand the locational logics and infrastructural needs from within.

Drawing on the *Inventaire Visuel de l'Architecture Industrielle* (Archive d'Architecture Moderne 1980), we identified where iron and steel workplaces were situated in the city. *Visuel* refers to both the selection procedure applied in the 1980s, i.e. according to the visual presence of a workplace in the streetscape, and to the rich photographic documentation and occasional blueprints.

Our first step consisted of filtering the 1671 industrial buildings featured in the inventory according to the workshops' (original) use for metal processing. Fifty-one premises of merchants, foundries, forges and steel construction companies, in general, were included in a digital and georeferenced database and subsequently projected onto a Brussels city map. Secondly, the architectural-typological properties of these buildings were assessed, such as spatial embedment in the urban fabric, the number of storeys, forms of hybrid usage and accessibility. To do so, the records and photographs of the *Inventaire Visuel* were supplemented with cadastral maps, building permits and (historical) aerial imagery. For those buildings that are still exploited for the same purpose today, on-site visits and interviews allowed detailed analyses of the spatial layout of these metal processing operations, such as the sequence of machinery, the walkways, access, and storage. Building on these two dimensions, i.e. geography and use patterns coupled with a typomorphological study, conclusions can be drawn in relation to the spatial organisation of the Brussels iron and steel building industry in the long run.

3.1 *The territorial distribution of iron and steel builders*

Due to the weight of the raw materials, the historical iron and steel production facilities were intricately linked to the local availability of the resources or the immediate access to cargo. Iron ores were imported from Sweden and American countries to Belgium. The iron ores were melted in blast furnaces into pig iron and subsequently smelted and rolled into steel profiles. As the main energy source for the blast furnaces was coal, metal producers such as Cockerill settled mainly in the Walloon coalfields of Liège, La Louvière or Charleroi (Wemans & Paternoster 1991) in the first half of the 19th century. The modernisation of the Brussels-Charleroi canal in the 1850s, complemented with the rapid expansion and densification of the Belgian railway network, disclosed Brussels' industries to the abundant supply of this new source of energy and brought the Wallonian steel production to its urban sales market.

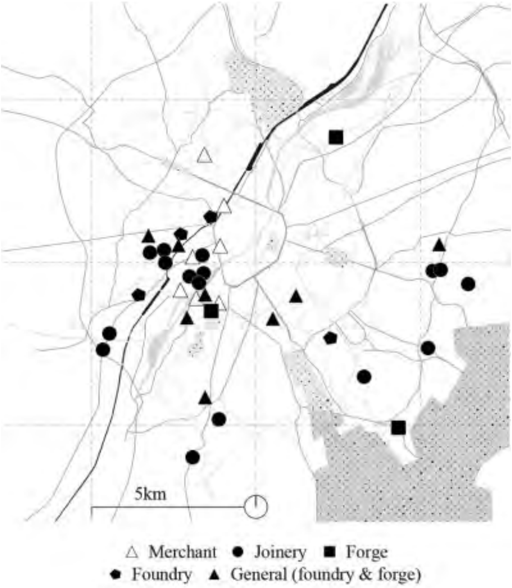

Figure 1. Geographical distribution of iron and steel merchants and workshops in the Brussels-Capital Region, based on the digitalization of the *Inventaire Visuel de l'Architecture Industrielle*.

In Brussels (Figure 1), local traders were generally grafted on the rail and waterways that supplied them with finished steel elements and pig iron in bulk. Considering the merchants listed in the *Inventaire Visuel*, this 'proximity to transport infrastructures' can occasionally be understood in its most extreme and direct way, with depots alongside the banks of the canal or with train tracks extending from suburban blast furnaces all the way into warehouses. Most steel traders did, however, not have the luxury of such an immediate link to the production sites or import networks, yet the geographical analysis shows that a deliberate location strategy to minimise transportation, was generally adopted. Moreover, the industrial and strongly mixed zones in the neighbourhoods surrounding these transport infrastructures offered merchants ample opportunities to establish a property with a large-scale footprint.

This finding confirms Alfred Weber's Least Cost Theory (1930) according to which the weight-losing processes, such as the cutting of standard elements to desired proportions by merchants, tend to settle near transport infrastructures. Moreover, while this location

Figure 2. UTIL company (former Peters and Van Droogenbroeck) in Rue de la Caserne in Brussels @ Belfius Postcards.

strategy was already discerned for timber merchants in the Brussels-Capital Region, the steel traders seem to adopt this principle to a greater extent.

The historical trajectory of the steel and iron merchant, UTIL, in Forest illustrates this inextricable relationship with transportation networks and infrastructures. In the early 1890s, Peters, Van Droogenbroeck & Cie, acquired an iron and steel trading estate from Van Mulder-Haberman who had settled 20 years earlier in a street parallel to where the Midi train station was located at that time (Figure 2). Yet, when the inner-city railway was decommissioned, the new owners erected a second, much larger depot in the nearby municipality of Forest, to have the possibility of trailing the carriage wagons directly into the newly built warehouse. Throughout the years, several takeovers followed: its proximity to the transportation network together with its vicinity to a rapidly expanding sales market, allowed UTIL to remain locally anchored until the 1980s.

The territorial mapping reveals how a majority of foundries, forges and steel joiners were, likewise, located in relative vicinity to their supplies, even though they could be considered as weight-gaining activities rather than weight-losing activities. Apart from the incentive to reduce transportation costs of the heavy steel, the strongly mixed areas along the canal axis and railway tracks also offered proximity of a growing market in the expanding city. Accordingly, the chain of metal processing activities in construction agglomerated in the municipalities of Anderlecht, Forest and Molenbeek-Saint-Jean. Conversely, however, timber joiners and cabinetmakers sought agglomeration effects with the intention of sharing costly infrastructures for processing timber (e.g. planing or milling machines).

3.2 *Infrastructural needs*

Holding the spatial organisation of the production processes of these iron and steel builders in the light of their location strategies demonstrates that such mapping analyses do not suffice to thoroughly understand the geography of building. Similar to how the architecture of timber workshops is dictated by specificities of the material (such as low-temperature processability, specific weight, and its ’living’ character), the preconditions for processing steel elements result in a different architectural layout. Typomorphological analyses strongly echo this observation, also within the iron and steel subsector (Figure 5). Indeed, the infrastructural needs that emerge from casting iron radiators, pipelines or columns are very different to those from forging ornamental railings and balustrade elements or welding pre-formed steel elements. How the spatial logics of these three metal processing activities have yielded alternative spatial footprints for foundries, forges and joiners is explored by identifying recurrent patterns of internal organisation and physical-spatial conditions.

3.2.1 *Foundries*

More than any other metal processing activity, iron casting activities were traditionally organised at a large scale, in coarsely mixed urban areas nearby water and railway infrastructures. On sizeable land, these foundries were organised as ’villages’ of workshops with allocated functions. The separation of these structures not only reduced the risk of fire spread but also created space between them to efficiently organise the logistics. Indeed, the scrap metal, stone, iron, coke and sand were transported from these separate depots to the furnace by carriages on internal railway tracks. From the ground floor inlet, the mixture was dropped into the furnaces to be drained at its bottom in the cellar after melting. Next, the substrate was hoisted into the sizeable casting room. Its open floor plan allowed the subsequent production steps from making sand moulds, casting the iron, letting it harden and demoulding. Afterwards, in a fettling workshop (Figure 3), the parts were sanded and treated against rust. The efforts to heat the furnace to 1500°c were only profitable when the molten iron was drained continuously. Not only did this imply the involvement of many workers, but also the storage capacity of resources and the size of the casting room were to be substantial.

Illustrative for such a sizeable foundry village, and confirming also the above-mentioned quest for scale economies, is the case of the Charlet foundry: originally founded in 1878, it was subsequently merged and acquired by Pierret, Stapper and ultimately Danckaert in the 1960s. During this reorganisation and mechanisation process, the company grew in terms of volume and productivity, but also in the physical extents of the workplace.

3.2.2 *Forges*

In contrast to these large iron foundries, the forging of mild steel was traditionally – and continuously –

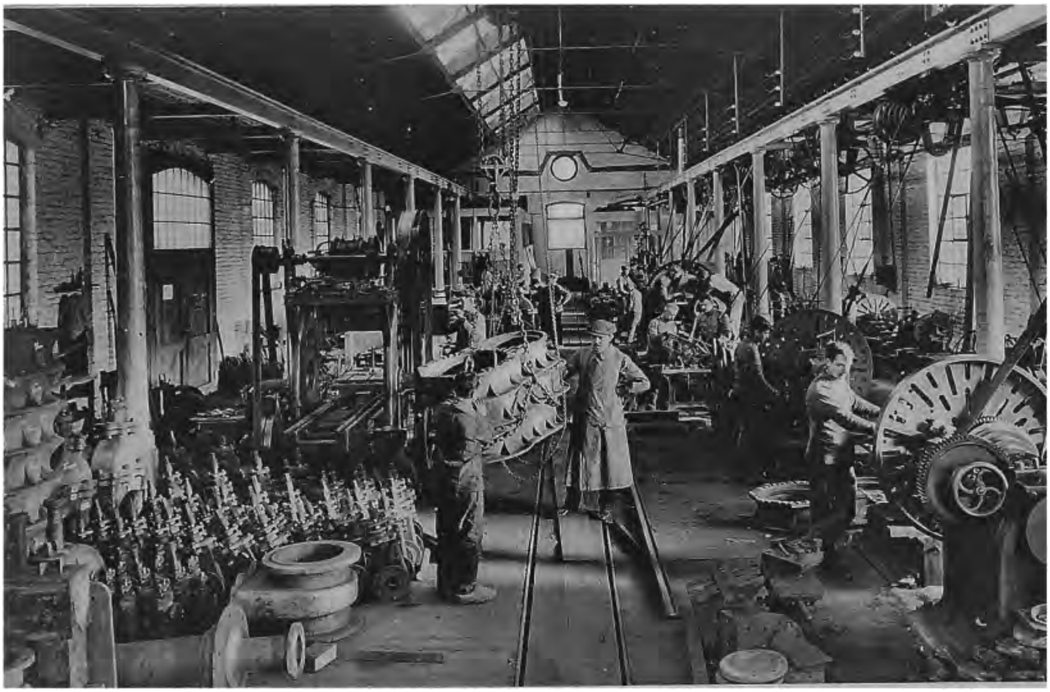

Figure 3. Fettling workshop of the Pierre Denis foundry in Forest © Delcampe Postcards.

organised by blacksmiths on a smaller scale. In consequence, they were able to settle in the strongly mixed fabric throughout the city, nearby their target market. Horizontally, the typical forge fitted within the small grain pattern of a terraced house with a garden in the back, while vertically, a private dwelling was erected on top of the workplace. The strong embedment amidst the demand side was facilitated by the entirely different production process (Figure 4). Unlike the foundries, which required separate warehouses to store the bulk resources, forgers departed from light, pre-formed steel profiles that could be stacked efficiently, resulting in a limited spatial footprint. Furthermore, as forgers did not need a furnace running over various floor levels, the entire production process was organised following a horizontal logic. This process commenced with heating the steel rods to a processable state in an open forge. Once heated, the glowing metal was subsequently hammered in several sequences to the desired shape on an anvil, which was later replaced by a hydraulic impactor. Given the rapid cooling time, the vicinity of these workstations to the open fire was critical, which underlines not only the possibility, but also the benefits of a minimal spatial footprint. Alongside this pounding heart of the workplace, a handful of assembly benches and spray booths served to finish the wrought iron elements.

The Grégoire forge was originally founded in Saint-Gilles in 1920, employing a relatively high number of iron and steelworkers. Yet, today, the workshop is run by two artisans, father and son Sénéchal, without any employees as they experience difficulties in recruiting labourers with deep expertise and skills. Moreover, the fragmentary demand and only partial mechanisation of the production process leaves little room for economies of scale.

3.2.3 *Iron and steel joiners*

As for the last category, iron and steel joiners were more versatile in their activities: besides (exceptionally) casting and hammering of iron and steel into the desired proportions, they mainly assembled components and structures for the building industry from the end of the 19th century onwards. Rather than applying heat, they employed brute or mechanical force to shape steel sheets into profiles and structures. The three basic operations involved were firstly cutting the rolled steel, then cold folding and eventually assembling these separate parts. Exceptionally robust installations, first mechanically driven and from the 1950s hydraulically, were used to cut and fold the metal. The footprint of these installations, as well as the necessary operating space around them, largely determined the maximum size of the metal structures to be made. Metal joiner workhouses, therefore, range from small-scale buildings – usually twice the size of a small forge – to industrial complexes as large as a foundry. This diverse functional and spatial logic is also reflected in the geography of metal joiners. When located in the dense and finely meshed urban fabric, they needed to drastically reduce the necessary storage space and called

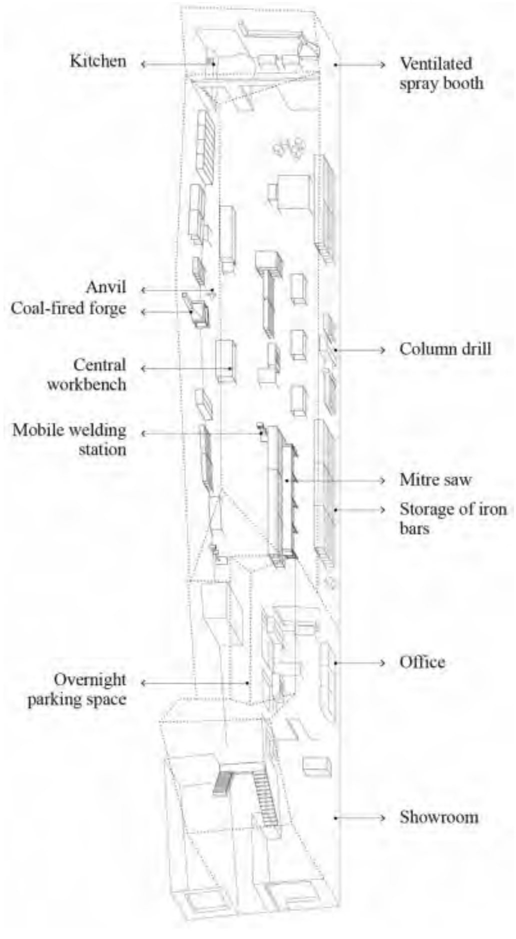

Figure 4. The internal organisation of a traditional forger's workshop in Saint-Gilles. Drawing by Forton and Vandyck.

upon merchants, forges and foundries that were historically anchored and located nearby, to supply them with readily available materials. The alternative of large areas of land was only affordable on the outskirts of the city.

4 CONCLUSION

With this paper, we aspired to sketch a comprehensive outline of the iron and steel construction industry in the Brussels-Capital Region, by taking into account small, medium and large-scale actors. In doing so, we have fundamentally contributed, on the one hand, to the observed knowledge gap concerning the long-term organisation of this subsector and, on the other hand, to the lack of a framework for anchoring, interpreting and assessing individual case studies in state-of-the-art construction history research. Building on extensive and varied source material, we related macroeconomic and spatial information for historiographical research into the urban construction industry.

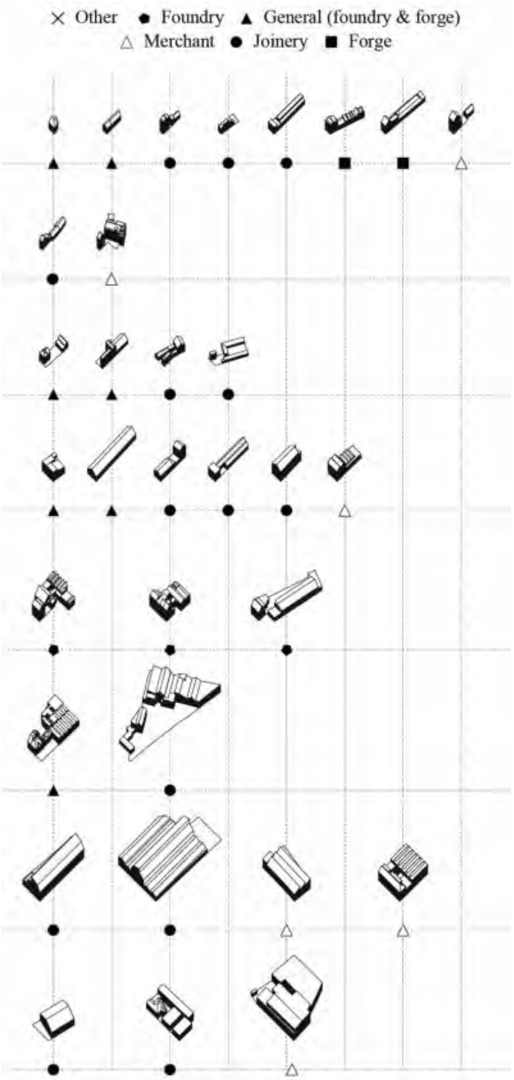

Figure 5. Axonometric overview of historical iron and steel workshops in the Brussels-Capital Region, depicting a selection of buildings listed in the *Inventaire Visuel* that continued to exist to date. Drawing by Forton and Vandyck.

From the quantitative analysis of enterprises and employment rates, it was concluded that throughout the 19th and 20th centuries in Brussels, there were two predominant, seemingly contradictory, yet complementary trends: on the one hand, an increase in average company size resulting from the drive towards economies of scale, and, on the other hand, a strong and sustained presence of small, mainly artisanal, companies that responded flexibly to changing demands and trends (Figure 5).

Studying the iron and steel subsector from a multilevel spatial perspective, we noticed a strong relation between the type of enterprises, their locational logic within the city, their spatial footprint and the internal

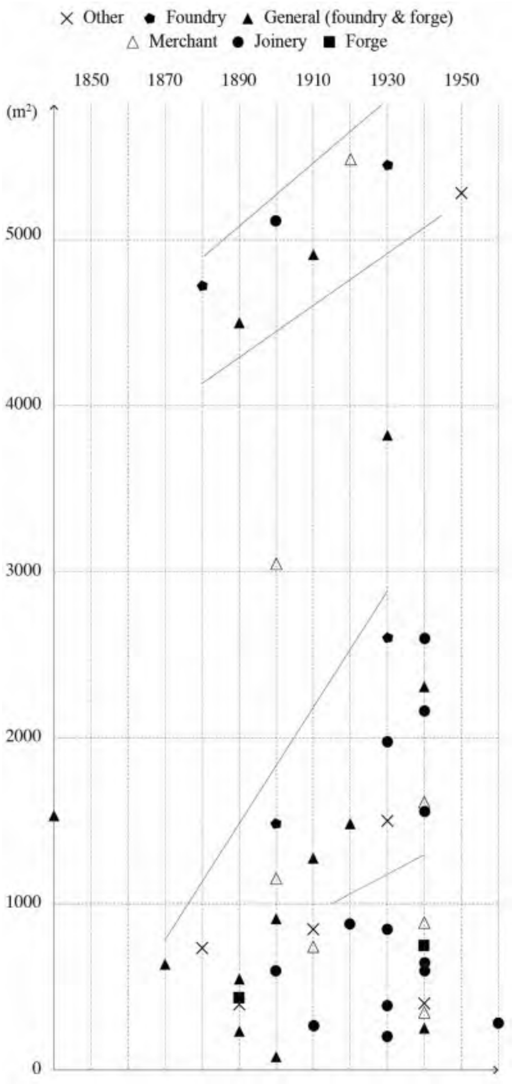

Figure 6. Relationship between the construction period and parcel size of historical iron and steel construction workshops.

organisation of their workspaces. The spatial constellations of builders' own premises, thereby, not only serve as potential heritage, but also as a tangible source to gain insight into the activities and organisation of the enterprise, as well as the socio-cultural and economic contexts in which they operate (Figures 6).

Outlining historical evolutions of the iron and steel construction industry's heritage, a clear dichotomy has traditionally emerged between small workshops for artisanal production (forges, certain joiners) in the residential urban fabric and particularly large plots in industrial zones near transport infrastructures (foundries, merchants). Moreover, a twofold trend seemingly emerging from the 1890s onwards is, on the one hand, an incremental footprint of both the smaller as well as the largest structures – such as those of general ironworks, foundries and steel joiners – and, on the other hand, the consolidation of an important share of smaller workplaces, including forges and small-scale steel joiners.

Building on these parallel correlations in the relationship between economic activity and employment on the one hand, and industrial production and infrastructure on the other, further research is needed to assess the relationship between corporate infrastructure and employment, paying specific attention to market share and productivity.

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History of Construction Cultures – Mascarenhas-Mateus & Paula Pires (eds)

Salvaging construction materials in Brussels, 1900–1925

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ABSTRACT: This paper studies the demolition and salvage process of construction materials in Brussels in the early 20th century (1900–25), a period that is generally considered a turning point in the reuse practice of construction materials but has not been researched in-depth. The paper is based on an analysis of the photographic collection of the Comité d'Etudes du Vieux Bruxelles, the building specifications of public sales of buildings to be demolished and municipal council reports. This gives insights into the process of demolishing buildings and the profile of the contractors involved, and offers a first glimpse of the selling and reusing of these building materials. With this case of the City of Brussels and through the study of these specific sources we aim to enlarge the knowledge of historic salvage of construction materials.

1 SALVAGING AND REUSING CONSTRUCTION MATERIALS

Today, reusing construction materials is again high on the agenda as it is considered one of the strategies within circular building to reduce waste and to decrease the environmental impact of the construction sector (Baker-Brown 2019). Although reusing materials has been a common feature in the construction sector for centuries, the practice came into disuse during the 20th century. The reuse of materials in this century is however hardly studied in the field of construction history (Bernardi & L'Héritier 2018; Hillebrandt et al. 2019; Stockhammer & Koralek 2020). The introductory chapter in the book on *Déconstruction et réemploi* (Ghyoot et al. 2018) covers the reuse practice in the 20th century throughout Europe and the USA and lists the main causes for the decrease of salvaging construction materials in the first third of the 20th century: the use of new, faster and more destructive demolition techniques; changing construction methods; and increasing labour costs. The chapter illustrates how this shift occurred with several events in various countries. For instance, due to the speed (45 days) of the demolition of the 13-year-old Gillender Building in New York in 1910, only few materials were salvaged, and in that same year Brussels' demolition contractors refused to demolish the *Caserne Sint-Elisabeth* if the time frame of three months was not prolonged (Ghyoot et al. 2018). The time pressure, raising wages and mechanization of the demolition process would further decrease the economic benefits of salvaging construction materials in the 20th century.

Although the constraints of time pressure and high wages are still valid today, new parameters such as environmental impact, life-cycle costs and material taxes are now taken into account. This changes the overall context and might further increase the demand for reused materials. However, there is still a long way to go to reintroduce the practice of salvaging and reusing materials in the construction sector, since there are only few insights into its historical organization and underlying infrastructure.

In this paper we focus on the early-20th century (1900–25) to gain insight in the organization of the salvage and reuse of construction materials when this practice was still active and flourishing, and we investigate the speed at which it fell into disuse. Brussels is taken as a case because large demolition works took place (Figure 1) and specific sources are available to uncover parts of the process, networks and infrastructure that were used by the demolition actors. The main consulted sources are a collection of photographs ordered by the*Comité d'Etudes du Vieux Bruxelles (1909–39)*, the building specifications of public sales

Figure 1. Vast demolition works were taking place in Brussels at the beginning of the 20th century. For instance, Rue des Douze Apôtres and Rue du Parchemin were demolished in 1909. *Collection Comité d'Etudes du Vieux Bruxelles © Bibliothèque artistique, ArBA.*

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Figure 2. The Public Warehouse was photographed before its demolition in 1911. *Collection Comité d'Etudes du Vieux Bruxelles © Bibliothèque artistique, ArBA.*

Figure 3. Demolition contractor Guillaume Sauvage had 120 days to demolish the former Minimes Prison in Brussels in 1922. *Collection Comité d'Etudes du Vieux Bruxelles © KIK-IRPA Brussels.*

of buildings to be demolished and the municipal council reports (1900–25), preserved in the City Archive of Brussels (CAB). In total, 25 building specifications were analysed concerning the demolition of various kinds of buildings and ensembles, ranging from immense public buildings such as the Public Warehouse (Figure 2), the Minimes Prison (Figure 3) or entire streets with more than 100 houses (Figure 1).

First, the context of the photographic collection is sketched. Afterwards, the practice of demolishing and salvaging construction materials in Brussels is analysed: the process, the different actors involved, and the steps taken towards selling and reusing these materials.

2 SALVAGE AND REUSE IN REMEMBRANCE OF THE OLD CITY

When Brussels became the capital city of the newly established country of Belgium in 1830, it underwent tremendous urban changes (Leblicq 1979). Infrastructure works to cover the Senne River in the 1860s erased large parts of the historic city centre. Although many, new large avenues were erected with luxury houses, apartments and monumental public buildings, protests against the mass destruction of complete urban districts and smaller heritage buildings arose. In this period, the Belgian Royal Commission for Monuments (1835) was mainly occupied with the protection of national and religious monuments such as castles and cathedrals, and was not focused on preventing the mass demolitions of the medieval fabric of the inner city (Meyfroots 2001). In 1903, the *Comité d'Etudes du Vieux Bruxelles* was established to study and document the architectural heritage of the 16th, 17th and 18th centuries in the Brussels' city centre and to compose a photographic album of characteristic buildings and architectural details (Ingelaere 2001; Leblicq 1979). This interest in preserving such heritage was not a Brussels phenomenon. In Antwerp, a commission (1882–85) was set up to decide on the preservation of relics from the oldest town centre, which was demolished due to the rectification of the Scheldt Quays (1874–85) (Dobbels 2011). In other countries, similar committees were also established, for instance in Lyon and Bordeaux and the *Commission du Vieux Paris* in 1897 (Meyfroots 2001). The systematic study of characteristic old buildings by the *Comité d'Etude du Vieux Bruxelles* was often interrupted by urgent photographic campaigns to capture districts and streets that were to be demolished in the context of urban renewal projects. In 1907–08 the Isabelle and Lombard streets were, for instance, photographed before remodelling the *Hofberg*. And the Putterie, Isabelle and Ter Arken neighbourhoods were photographed before the demolition works of the North-South railway connection started. Although these photographs focused on the still existing and soon-to-be-demolished buildings, the collection of over 1500 photographs, taken from 1903–39, also captured (by accident) part of the demolition process, tools and workers. When looking carefully at the photograph (Figure 4) of buildings to be demolished in Rue Montagne de Sion, one can observe that the window frames were carefully dismantled in their entirety.

Figure 4. Window frames are taken out of the buildings before demolishing the houses on Rue Montagne de Sion.*Collection Comité d'Etudes du Vieux Bruxelles © Bibliothèque artistique, ArBA.*

Figure 5. Sorting materials (brick, timber, blue stone) at the demolition site of Chartreux Chapel in 1905. Rue des Fabriques 1 in Brussels. *Collection Comité d'Etudes du Vieux Bruxelles © KIK-IRPA Brussels.*

Figure 6. The facade of the *Gouden Huyve* situated in Rue de l'Etuve 13 was carefully dismantled in the 1920s and reconstructed in 1929 next to Sint-Nicolas Church. *Collection Comité d'Etudes du Vieux Bruxelles. © KIK-IRPA Brussels.*

In the foreground, two horse carts are waiting to be filled with salvaged bricks. In Figure 5, stone, bricks and timber are sorted during the demolition of a chapel in 1905.

From 1906 onwards, the committee played a more active role in heritage conservation. The committee members not only convinced the City of Brussels to acquire some important buildings (such as the Bellone House in Rue de Flandre) but they also promoted the relocation of buildings with heritage value whose preservation in situ was impossible due to planned demolition and urban transformation works. Their proposal to create an open-air museum of city fragments at the exposition site *Cinquantenaire* was not supported. Yet, the facade of the *Gouden Huyve* (Figure 6) was carefully disassembled in the 1920s and rebuilt against the Sint-Nicolas Church in 1929. Similarly, the facade of the Sint-Anna Chapel was reconstructed adjacent to the Magdelena Chapel (Meyfroots 2001). Smaller elements with architectural qualities such as doors and staircases were also documented, photographed and salvaged on request of the committee and stocked by the City of Brussels (Meyfroots 2001).

For the *Comité d'Etudes du Vieux Bruxelles*, the preservation of heritage buildings and architectural details was a way to raise public awareness about the old city centre. Since they focussed on structures and details with high architectural quality constructed before 1850, their activities do not represent the overall salvage practice. To gain more insight in the broader context of demolition, salvage and reuse of construction materials, the public sales of buildings to be demolished are studied in the following paragraphs.

3 BUILDING SPECIFICATIONS OF DEMOLITION WORKS

In contrast to many developments at the outskirts of Brussels, the infrastructure works within the densely populated city centre of Brussels were always accompanied by demolition works. In the period 1900–25, the City of Brussels published public tenders for demolition works in the framework of the development of the Maritime neighbourhood, the realisation of a railway that connected the stations in the North and the South and the redesign of the *Hofberg* to connect the upper and lower city. These works resulted in the complete destruction of, among others, the former Putterie and Isabelle neighbourhoods. The public tenders, together with the offers of the contractor(s) can be consulted in the City Archive of Brussels (CAB) in the *Actes Administratifs* (AA), that contain a yearly overview of all tenders and offers.

Figure 7. Reconstruction of the facade of *Gouden Huyve* next to Sint-Nicolas Church. © Wouters.

For this paper, the *Actes Administratives* of the period 1900–25 were consulted. The annual books of the war years 1915–19 are, however, not preserved in the archive. In the studied period, the City of Brussels launched 25 tenders, *Vente publiques des bâtiments à charge de démolition*, unevenly spread over the years: varying from zero to six calls a year with a peak in 1904–11. The tenders for demolition followed the rhythm of the approval of urban transformation plans and the resulting forced appropriations. The buildings to be demolished were both private (houses) and public buildings (schools, a prison, a public warehouse).

The public tender documents, *Vente publiques des bâtiments à charge de démolition*, start with an explanation of the buildings to be demolished. It is mentioned that the buildings were sold in their actual state, excluding street pavements, gas and water service installations. In two projects, additional paragraphs are added. The building specification of 1910 covering demolition works in the Isabelle neighbourhood additionally mentions that the frame and woodwork of a door and window of the house in Rue Terarken 4 was excluded from the sale (CAB AA 1910: 7833). These architectural details were probably salvaged on request of the *Comité d'Etudes du Vieux Bruxelles*, as their 1907 photographical campaign depicts the street and the facade (Figure 8).

In 1914, not only architectural elements such as interior doors and a cast iron staircase, but also technical equipment such as flush toilets with lead pipes and accessories, zinc discharge pipes, service taps and timber roof trusses were excluded from the sale of five out of 23 houses in Rue Madeleine (CAB AA 1914: 9083).

Figure 8. The door and window frame at Rue Terarken 4, depicted via a photographic campaign in 1907, were salvaged during the demolition of the street in 1910. *Collection Comité d'Etudes du Vieux Bruxelles. © KIK-IRPA Brussels*.

Next to a paragraph explaining the procedure about how and when to hand in the offers, the demolition works and the time limit for completion was discussed. The documents also mention the penalties in the event of non-completion at the end of the fixed deadline. In 1900, the penalty mounted to a fixed amount per day and from 1910 onwards this amount was fixed for the first fifteen days and doubled for the following ones. The time limit for completion of the works varies from fifteen days, for a small project in 1900, to six months, for the demolition of the large Public Warehouse in 1910 (Figure 2). The time limit was proportional to the size of the work. After 1910, however, the minimum period mentioned in the building specifications is three months, even for relatively small works. Ghyoot et al. (2018) defines the year 1910 as a turning point in the reuse of construction materials in Brussels. In that year, Brussels' contractors did not agree with the time limit mentioned in the building specifications of the demolition of the *Caserne Sint-Elisabeth*. The contractors requested an expansion of the period from three to six months, otherwise they would charge money to demolish the building instead of paying to carry out these demolition works (Ghyoot et al. 2018). In all 25 building specifications and the corresponding offers in the time period 1900–25 that were studied, the contractor proposed a budget to demolish the buildings. The turning point, when contractors were paid to demolish a building instead of paying to salvage the materials themselves, is not visible in our study. However, the number of tenders issued by the City of Brussels decreased after 1910 in favour of combined tenders where demolition works were included in the specifications of new buildings to be erected (Baes 2021).

Furthermore, the building specifications stipulated that the contractor had to build a solid, timber fence around the demolition works and that he could not use public spaces to stock materials.

When demolishing a terraced house, the roof of the adjacent building and the common wall had to be covered with tiles.

Attention had to be paid not to interrupt the rainwater runoff. Exposed side facades had to be flattened: bricks coming out of the wall had to be removed and openings created when taking out timber beams had to be filled. If a new wall was to be constructed to demarcate the plot, no recovered materials could be used for that purpose. This is somewhat surprising, as all demolition works generated salvaged bricks that could be reused for such works. The building specification of 1914, issued just before the First World War, stated that salvaged brick and timber had to be used to construct a wall, the fence and the gate. However, these reused materials had to be in perfect condition and their quality was judged by the Administration's agents (CAB AA 1914: 9083).

The contractor also had to comply with the *Cahiers des Charges Générale des entreprises de travaux de la Ville de Bruxelles (1884)* that imposed obligations with respect to the workers: the contractor had to pay his workers the minimum wage and had to insure them against accidents. Lists of these minimum wages were available at the City Administration. In some building specifications, these lists are included. In 1905, the minimum wages for 36 professions in the construction sector are mentioned: the wage per hour of workers ranged from 35 to 55 centimes, the wage of helpers was about half of that. The profession of *démolisseur* was mentioned for the first time in such a list in 1910. The minimum wage for a demolition worker was 45 centimes and thus lower than the wage of masons and carpenters (50 centimes), yet higher than the 40 centimes for *charretiers et terrassiers* who guided the carts and moved the earth (CAB AA 1910: 7695). The building specifications included regulation of working hours, which could not exceed ten hours a day. The workday was further reduced to a maximum eight hours in the building specifications of 1922. These 1922 specifications also contained an article on the treatment of horses: "Horses used for the transport of materials must be fit for their intended purpose, free of sores and lameness. They shall not be overloaded or mistreated" (CAB AA 1922: 8935).

4 DEMOLITION ACTORS

The *Actes Administratives* include both the building specification and the offer of the contractor who was appointed the works. From the 1920s onwards, an overview of all submissions was added, which allows to compare the offers and get insight in the group of contractors submitting an offer. As such, we know that eight contractors sent in offers to demolish the former prison, Minimes, in 1922. Demolition contractor Guillaume Sauvage was granted the works as he offered 22,477 fr. The difference with the lowest bid was quite large: demolition contractor Pierre-Jules Jacquemyns bid only 7550 fr. (CAB AA 1920: 9835). For the offers submitted before the 1920s, some comparison is possible when the work was split up in different lots and when contractors sent in offers for several lots. The tender for the demolition of the Public Warehouse that was published in 1910, was split in three lots: (1) main building, (2) adjacent small office building and (3) iron fence. The contractors Guillaume Van Humbeeck and Louis Peppe were assigned the first two lots offering respectively (1) 52,000 fr., (2) 5520 fr., and (3) 1600 fr. for the works. The contractors Henri Wyckmans and Adam Driessens were assigned the third lot offering respectively (1) 32,825 fr., (2) 4775 fr., and (3) 2500 fr. for the lots. (CAB AA 1910: 7881) Although only these two offers of bidding contractors were included in the *Actes Administratifs*, it is again clear that the offers greatly fluctuated.

As the majority of the works was split up in two to four lots, the 25 demolition works represent 43 lots that were assigned to 26 different contractors. Contractors Jean Vandensanden (1905–07), Louis Peppe (1909–11) and Guillaume Van Humbeeck (1907–22) were the most successful ones as they were involved in respectively three, four and five demolition projects.

From 1900 onwards, the large majority of appointed contractors profiled themselves in their offer as 'demolisher' or 'demolition contractor'. They were also mentioned with the same job description in the *Annuaire alphabétique belge du Commerce et de l'Industrie. Edition Bruxelloises.* The contractors Jean Vandensanden, Antoine Vandesavel, Guillaume Van Humbeeck and Jacques Van Humbeeck were successful bidders and acted as (independent) demolition contractors. Other bidders combined the demolition of buildings with the selling and buying of salvaged materials. They also profiled themselves as demolition contractors in their offer, yet in the *Annuaire*, they were mentioned as 'demolition contractor and seller and buyer of old construction materials'. Contractors François Dufour, Henri Elsoucht, Louis Huyghe, Pierre-Jules Jacquemyns, Louis Peppe and Léopold Vanhaelen belonged to that category (Figure 9). Very often, contractors teamed up when sending in an offer.

VENTE ET ACHAT
de vieux matériaux et métaux,
379, Chaussée de Louvain,
Louis PEPPE
Entrepreneur de démolitions
MAGASINS :
379-381 et 383, Ch. de Louvain
Schaerbeek - Bruxelles
(Près de la place Dailly)
TRAMS 59, 60, 61, 72 et 74

ENTREPRISE GÉNÉRALE DE **DÉMOLITIONS**
P. J. JACQUEMYNS
Téléphone 107.21
BUREAUX : 45
MAGASINS : 47
Rue des Goujons
MAISON FONDÉE EN 1868
ACHAT - VENTE DE MATÉRIAUX

Léop. Vanhaelen
ENTREPRISE DE DÉMOLITIONS
MATÉRIAUX, MÉTAUX et MATÉRIELS de REMPLOI
— ACHAT ET VENTE —
75, rue Ropsy-Chaudron, 75, BRUXELLES-MIDI

Figure 9. Advertisements of demolition contractors Louis Peppe, Pierre-Jules Jacquemyns and Léopold Vanhaelen in the *Annuaires Alphabétique Belge du Commerce et de l'Industrie. Edition Bruxelloises. 1925*. © City Archive of Brussels.

Louis Peppe teamed up successfully with demolition contractors in four projects (1909–22). The bid was thus always submitted by a contractor, whether or not linked to someone who was also specialised in selling or reusing the construction materials. The offer for the demolition of houses on Rue de Flandre in 1907 is, however, an exception. The bid was not initiated by a contractor, but by a truck driver, F. Vandermeeren, who teamed up with second-hand material sellers Jules Bardiaux and Aloys Spilthooren (CAB AA 1907: 6697). Although exceptional, it was not illogical as the transport of materials and rubble was an important part of the demolition works.

Although these demolition contractors and the sellers and buyers of old construction materials are important actors, not much is known about them. Through the *Annuaires* we were able to trace the addresses of their offices and depots and get a view of their geographic distribution within the city. Most of their depots for salvaged materials were located near the canal and the railway (Rue d'Allemagne, Rue Goujons, Rue Ropsy-Chaudron) in the industrial neighbourhoods. The location strategy of these second-hand-material sellers therefore seemed similar to the companies that were selling new construction materials to the City of Brussels (Vandyck & Degraeve 2019). The depots of Brussels' two largest material suppliers were also located near the canal and the railways: that of Ackermans at Quai de Matériaux and that of Fontaine at Quai de Willebroeck (Baes 2021). Today, none of the depots of salvaged materials used by the mentioned demolition contractors still exists, as they have all been demolished.

- TRAVAUX DE DÉMOLITIONS -
COMMERCE DE MÉTAUX

ACHAT
D'USINES AVEC OU SANS MATERIEL
A CHARGE DE DEMOLITION

EN MAGASIN
PORTES - CHASSIS - ESCALIERS
GITES - CHEVRONS
POUTRELLES - ANCRAGES
PAVEMENT - PIERRES BLEUES
ETC., ETC.

HENRI ELSOUCHT
Chaussée d'Anvers, 283 :: Bruxelles
TÉLÉPHONE Br. 4446

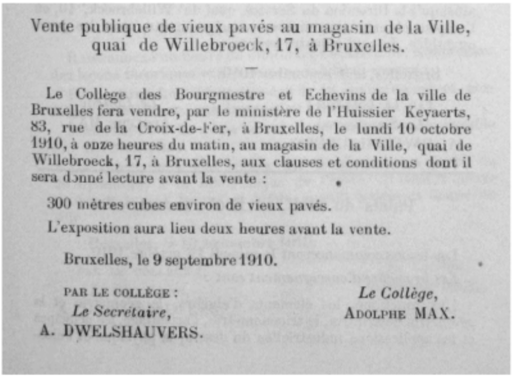
Bruxelles, le 17 Août 1922

Figure 10. The Brussels' demolition contractor Henri Elsoucht explains to a client in 1922 that he can sell eight salvaged steel trusses in perfect condition. © Delcampe.be.

5 SELLING SALVAGED MATERIALS

The analysis of 25 demolition projects issued by the City of Brussels in 1900–25 shows that contractors paid large amounts of money to demolish a building and transport the materials to depots. How profitable was this business and to whom could they sell the salvaged materials afterwards? These important questions could not be answered by the sources analysed. Studying archives of demolition contractors would be very relevant, yet until now these could not be retrieved. The letter, sent in 1922 by demolition contractor Henri Elsoucht, (Figure 10) in which he is actively seeking a customer for the sale of eight salvaged metal trusses, is indicative of the importance and large potential of such (still to be discovered) demolition contractors archives.

To gain some insight into the selling of salvaged building materials, we analysed the public sales organised by the City of Brussels in 1900–25. A *Vente publique d'objets trouvés, vieux matériaux et objets sans emploi* was regularly organised at the City material warehouse at Cail-Halot. (CAB *Bulletin Communal* 1900–23) These announcements of the public sale of found objects, old materials and unemployed objects contain a general list mentioning the sale of items such as old furniture, beds, baskets, ladders, wheelbarrows, handcarts, and also architectural components such as stairs, doors, frames, shutters, and marble fireplaces, and construction materials such as blue stone



Vente publique de vieux pavés au magasin de la Ville,
quai de Willebroeck, 17, à Bruxelles.

Le Collège des Bourgmestre et Echevins de la ville de Bruxelles fera vendre, par le ministère de l'Huissier Keyaerts, 83, rue de la Croix-de-Fer, à Bruxelles, le lundi 10 octobre 1910, à onze heures du matin, au magasin de la Ville, quai de Willebroeck, 17, à Bruxelles, aux clauses et conditions dont il sera donné lecture avant la vente :

300 mètres cubes environ de vieux pavés.

L'exposition aura lieu deux heures avant la vente.

Bruxelles, le 9 septembre 1910.

PAR LE COLLÈGE :
Le Secrétaire,
A. DWELSHAUVERS.

Le Collège,
ADOLPHE MAX.

Figure 11. The City of Brussels organised public sales of old cobblestones on a regular basis. *Ville de Bruxelles. Bulletin Communal 1910* © City Archive of Brussels.

and cast-iron scrap. Such a public sale was organised ten times in the studied period of 25 years. However, these general announcements do not allow us to determine precisely how many construction materials were sold and to whom. Yet, the fact that the City of Brussels continued to organise the sales, means they will have been profitable.

The City of Brussels also organised a sale of old cobblestones one to five times a year at the City's material depot at *Quay Willebroeck* 17 (Figure 11). The yearly number of cobblestones sold varied from 300 m^3 to 2950 m^3. The large amounts sold in 1909–12 originated from the demolition works in the Maritime neighbourhood and the Public Warehouse (CAB Bulletin Communal 1902–23).

6 CONCLUSIONS

The first third of the 20th century is often referred to as the period when reusing construction materials got out of practice. This study demonstrates that the City of Brussels continued to issue public tenders to demolish buildings in the period 1900–25 and that contractors continued to offer bids to salvage the materials. The bidding contractors profiled themselves as specialised contractors in demolition works and often teamed up with sellers and buyers of salvaged building materials. In 1925, there were still many demolition contractors active in Brussels, willing to submit bids as is demonstrated by the eight bids for the demolition of the prison in 1922. The overall decline in the reuse of construction materials that is mentioned in literature, is thus less evident in the sources we have studied. However, there is a clear decline in the number of public tenders that was issued by the City of Brussels for demolition works after 1920.

The photographs of the *Comité d'Études du Vieux Bruxelles* depict possible reasons for the long period in which the salvage of construction materials was common practice in the City of Brussels. The pictures show that the buildings to be demolished were constructed according to the traditional construction techniques (brick, stone, timber, lime mortar) making them easy to dismantle. Moreover, we do not see workers using mechanical equipment which means the materials were dismantled carefully, they were less damaged (when compared to mechanical demolition works) and could be reused and sold more easily.

Further research will enlarge the period and geographic area studied and will include demolition contractors' archives.

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Building the Beaux-Arts in the Steel City: Pittsburgh's Rodef Shalom Synagogue, 1906–1907

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ABSTRACT: This paper examines the construction in 1906–07 of Rodef Shalom Synagogue in Pittsburgh, Pennsylvania. The relationships between the Paris-trained, New York-based architect, Henry Hornbostel; the Philadelphia-based general contractor, Thomas Reilly; the Rodef Shalom building committee, and a host of sub-contractors, material suppliers and agents on the building site is unusually well-documented and includes the involvement of the New York-based Guastavino Company for the construction of the building's signature dome. Emerging from the Rodef Shalom correspondence is a clear picture of the sequencing of design documentation as building work progressed, the central role of the general contractor in managing the project, and the hierarchy in communications between architect, client and general contractor. The challenges of coordinating a complex project at a distance relied on correspondence, photography, telephones, telegrams and railways, which together contributed as much as on-site agents to shaping the construction process. Special thanks to Martha Berg and the Rodef Shalom Congregation for permitting me to consult material in their archives in early 2020.

1 INTRODUCTION

In the course of the 19th century, new communication, fabrication and transportation technologies exercised a transformative impact on design education and building practice, reshaping architecture as a profession and the management of building projects. Architecture in the United States reveals the impact of new technologies in both the careers of architects and the nature of building. Trans-Atlantic transportation networks made it possible even before 1850 for individuals such as Richard Morris Hunt and later, Henry Hobson Richardson, to pursue training at the Paris École des Beaux-Arts, to travel around Europe and to launch careers back in the United States that would imprint American cities with principles of French academic classicism and lessons learned from models on the Old Continent. At the same time, the use of factory-produced metal structural elements sped up construction, permitting buildings of unprecedented heights to rise in unprecedentedly short periods of time. What had been largely artisanal a century before was by 1900 a business. Architects on the cutting edge who worked with sophisticated clients on complicated buildings projects were businessmen working in offices who collaborated with other professionals, businessmen and manufacturers to create architecture.

Of many possible examples, the career of Henry Hornbostel (1867–1961) is worth considering as exemplary of those many young American men who in the late 19th century sought advanced architectural education in Paris before creating a successful practice in the United States. In the space of 50 years, Hornbostel and his various partners completed over 200 building projects from New York to California (Kidney, 2002; Rosenblum, 2009). Though Hornbostel's office was situated at 63 William Street in Lower Manhattan, the bulk of his work was located in Pittsburgh, some 600 kilometers away. A city of extraordinary wealth and manufacturing output, home to industrial titans who would become outstanding patrons, Pittsburgh is a city where the impact of French-trained architects is especially apparent in building projects executed from the 1880s to World War II. Pittsburgh is consequently a notable example of the American "City Beautiful" movement, which sought to reshape even the most polluted industrial metropolis into a showplace of culture and sophistication through monumental civic buildings.

While it is possible to sketch out in general terms the impacts of new methods and technologies on the design and execution of building projects, seeing exactly how those methods and technologies were implemented in the day-to-day execution of buildings is possible only in rare instances where documentation survives attesting to the activities of an array of agents, including the architect, clients and building committees, general contractors, sub-contractors and material suppliers. That documentation – letters, telegrams, records of telephone calls, drawings, photographs – was a key part of the process of execution. Each is a technology that made it possible to imagine ways of interacting and communicating instructions at a distance. While railroads abridged distances between

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Figure 1. Rodef Shalom Synagogue. Photo by author.

far-flung sites of production, telephone and telegraph lines made instantaneous communication possible that could further speed up construction, shortening the time between ordering materials, their fabrication, shipment and assembly.

By the early 20th century, building components such as steel beams and terra cotta ornaments were custom-made at factories and shipped to building sites in a just-in-time fashion. General contractors who were responsible for ordering all the parts of a building and for assembling them on-site thus played the central role in orchestrating building construction and realizing an architect's designs. The role of the general contractor, however, is often ignored and difficult to discern. We are thus left guessing at what role they played in shaping design decisions that contributed to the final appearance of buildings, and how they interacted with architects, clients, sub-contractors and material suppliers. For a Beaux-Arts-trained architect like Hornbostel, how were abstract design-principles learned in France translated by his contractors into actual buildings in the American context?

This article will focus on the construction of Hornbostel's Rodef Shalom Synagogue in Pittsburgh (Figure 1), an exemplary instance where the daily correspondence between architect, contractor and other agents involved in the project survives. This correspondence was not casual: it documented decision-making at every step in the construction process. Correspondence was also the basis of a lawsuit between Rodef Shalom and the general contractor. The mass of correspondence is considerable: in a letter to the congregation, Hornbostel confessed to struggling with the volume of paperwork and with identifying documents showing who was responsible for changes to the design and when (RSCA, file 9, 30 July 1912).

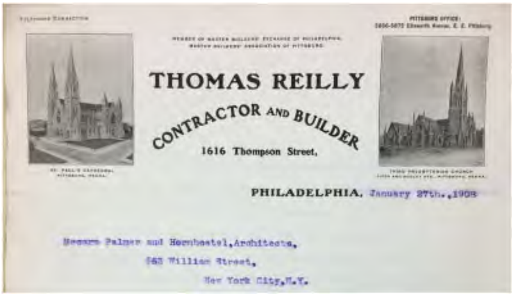
2 PLANNING RODEF SHALOM

Built in 1906–07, Rodef Shalom Synagogue is located a few blocks from the Carnegie Library, Museum and Music Hall, Saint Paul's Cathedral, the campuses of the University of Pittsburgh and the Carnegie Technical Schools, and a host of clubs, sporting venues and public spaces that make up the city's Oakland cultural center. The prominent location and novel architecture of the synagogue made a statement about the position of Pittsburgh's Reformed Jewish community in the local and national contexts, which, like the Catholic diocese, the universities and Andrew Carnegie himself, were staking out positions as leaders in civic beautification and social betterment that affected the city as a whole and the outlying region (Kidney, 2002, 110–13; Rosenblum, 2009, 189–200; Rosenzweig & Chaffey, 2001; Toker 2009, 283–85).

Despite having inaugurated a new synagogue downtown in 1901, by 1905 the leaders of Rodef Shalom felt that a move to more spacious quarters in a healthier, more bucolic neighborhood was justified, based on a spike in membership and demographic trends that favored a location in the city's wealthy east end (Feldman, 1986, 187). A site was purchased on 22 April 1905, a program developed with the assistance of consultant Warren P. Laird, professor of architecture at the University of Pennsylvania (approved by the building committee on 12 June), and designs from six architects invited to participate in a limited competition received by 9 September (two Pittsburgh firms: Allison & Allison and Charles Bickel; three New York firms: Palmer & Hornbostel, Pilcher & Tachau, and George B. Post & Sons; the Detroit firm of Albert Kahn). The winning firm – Palmer & Hornbostel – had burst onto the Pittsburgh scene in 1904 as winners of a national competition for the Carnegie Technical Schools, a sprawling campus of pavilion-style buildings designed to house spaces for the instruction of local youth in the applied arts and sciences so necessary for the city's and the nation's exploding industrial and manufacturing sectors.

The building committee was intent on completing their new synagogue by September 1906, a turnaround time of barely seven months from the moment bids were received from contractors based on revised drawings and specifications sent out in early January of the same year. According to the competition program, the cost of the building was not to exceed $150,000 but after initial bids were revised, the building committee sought authorization from the congregation to set the total construction cost at $250,000 (RSCA, Trustees Minutes, 28 Jan. 1906). By 1 February 1906, the contractor – Thomas Reilly of Philadelphia – had been chosen to execute Palmer & Hornbostel's design. Reilly's competence and efficiency were demonstrated by the completion the same year of the monumental Saint Paul's Cathedral two blocks from the site of Rodef Shalom Synagogue.

Reilly was a large-scale firm specializing in religious buildings, especially for the Catholic Church. Despite being based in Philadelphia, buildings in Pittsburgh were Reilly's most notable constructions: views of both Saint Paul's Cathedral and the Third Presbyterian Church further along Fifth Avenue figure at the top of Reilly's letterhead (Figure 2). Thomas Reilly himself oversaw multiple projects simultaneously in far flung locals; he must have had secretarial support



THOMAS REILLY
CONTRACTOR AND BUILDER
1616 Thompson Street,
PHILADELPHIA, January 27th.,1908

Messrs Palmer and Hornbostel,Architects,
63 William Street,
New York City,N.Y.

Figure 2. Thomas Reilly Contractor & Builder. Letterhead, 1908. Courtesy of Rodef Shalom Congregation Archives.

for handling payroll and managing correspondence, given the volume of letters produced for Rodef Shalom alone. Reilly also employed his own draftsmen who produced detailed drawings based on the architect's designs. On 8 May 1906, for example, Palmer & Hornbostel expressed their dissatisfaction with drawings supplied by Reilly for the bronze grill over the main entrance of the synagogue, an important decorative element one would expect the architects to design, and for which Palmer & Hornbostel did ultimately provide their own drawings (RSCA, file 5, Palmer & Hornbostel to Reilly).

3 BUILDING RODEF SHALOM

A week before a contract was signed with the building committee (14 February 1906) and well before receiving complete construction documentation from the architects, Reilly was at work on the site of the future Rodef Shalom Synagogue. The bid documents consisted of only 15 drawings and a 115-page typed specification. Correspondence reveals that in the course of construction, Palmer & Hornbostel produced over 400 sheets of drawings for the building. What is clear from the outset is that construction drawings were produced throughout the building process and made available to the contractor as they were generated – sometimes much later than Reilly requested them.

The synagogue consisted of two principal elements: a large domed auditorium facing Fifth Avenue with seating for 1,450 and a two-story Sunday school building attached at the back, containing eight classrooms with a total seating capacity of 250, plus cloakrooms, lavatories, two parlors, a library and a study for the Rabbi (the Sunday school wing has been demolished) (Figure 1). From the moment Reilly was chosen as general contractor, he expressed concern about the structure of the dome. In Palmer & Hornbostel's competition drawings, the dome was to be built on a steel truss framework, but by 1 February 1906, the architects were contemplating a thin tile vault to be executed by the firm of Raphael Guastavino (Parks & Neumann 1996, 52–3; Ochsendorf, 96).

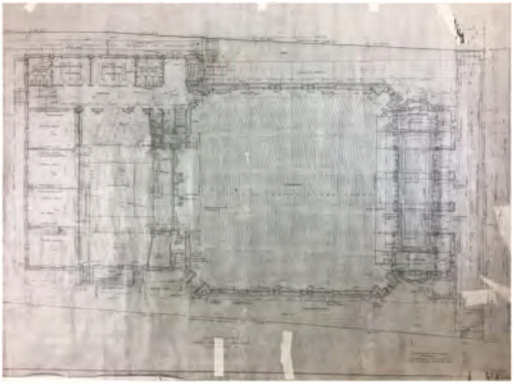


Figure 3. Rodef Shalom Synagogue, plan. Fifth Avenue entrance to the right. Courtesy of Rodef Shalom Congregation Archives.

Early in the construction process, Reilly signed contracts with materials suppliers for elements such as hardware (12 February 1906), custom-designed metal gates to be fabricated by a firm in Toledo, Ohio (13 February), wood paneling for the interior of the auditorium to be produced by a firm in Upstate New York (26 February), and sheet metal for the auditorium skylight to be made in Philadelphia (14 March). Contracts with other suppliers and sub-contractors were more problematic since full sets of drawings were required before costs could be determined. Notably, (1) glazed polychrome terra cotta elements which are such a distinctive part of the overall aspect of the building and that were produced by the Perth Amboy Terra Cotta Company of New Jersey, and (2) the dome designed and built by Guastavino.

As early as 21 March 1906, less than two months into the construction process but with the completion date in late summer already looming, Reilly expressed concern about delays holding up the building. These delays were the product of a number of factors: (1) the slowness of the architect producing detailed drawings for elements like terra cotta and woodwork that were fabricated off site; (2) the need to change parts of the design during construction either because the architects had not anticipated how elements like heating and ventilating equipment fit into the structure or due to requests made by the building committee; (3) the decision made by the architects after Reilly accepted the contract to build the auditorium dome using Guastavino's tile system rather than steel.

As the general contractor supervising the building site and coordinating the fabrication of elements needed at different stages in the construction process, Reilly was the central figure in the realization of Rodef Shalom Synagogue, acting as intermediary between the architects in New York and an array of fabricators and sub-contractors, many not in Pittsburgh. The key relationship with the client, however, was the special purview of the architects. Correspondence demonstrates that the architects shaped the impression of the construction process for the building committee but also that the building committee was aware of delays caused by the architects.

3.1 *Causes of delay*

Already on 8 March 1906, Reilly expressed concern to the architects about delays in obtaining detailed drawings, motivated by his "anxiety to complete this work in record time" (RSCA, file 5). On 29 March, Reilly reiterated his concern about not being able to complete the building on time if he did not receive details as requested from the architects.

Slowness in construction was aggravated by a carpenters' strike in Pittsburgh that began in May 1906. The strike propelled Reilly to state on 2 May that he would need an extension in the contract time. Alleging that the architects were slow to send needed drawings, Reilly threatened on 2 June to stop work for lack of information, to which Palmer & Hornbostel responded on 4 June that "we deny his charge that the work is held up due to lack of details" (RSCA, file 11). By this stage, four months since Reilly began work, the walls of the auditorium were well advanced and he was almost ready to set the wood frames in place for six large stained-glass windows, details which Palmer & Hornbostel stated on 2 June would be sent imminently. These and other wood components were to be manufactured by the Batavia & New York Woodworking Company in New York State and shipped to Pittsburgh by rail. Reilly received the drawings (sheet #307) of the auditorium windows on 7 June; on 16 June he suspended construction – the on-going carpenters' strike meant that wood centering could not be built for the dome. At the same time, lack of terra cotta elements for the exterior walls resulted in Reilly laying off his bricklayers. In late June, Palmer & Hornbostel acknowledged they had not supplied Perth Amboy Terra Cotta with drawings soon enough for elements to be fabricated as needed for installation, writing to Reilly on 27 June 1906 to say they would meet with Perth Amboy to "straighten out" details (RSCA, file 5).

The coordination of interior systems also caused difficulties that slowed construction since different sub-contractors were responsible for heating, electricity and wall plastering. Reilly was compelled to stop work on the Sunday school on 16 October 1906, for example, because the heating contractor hadn't installed pipes in time for the plasterer to complete interior walls. Reilly wrote to the architects at the time saying that: "all of us are likely to get into trouble if there is much more delay in finishing the Sunday School Building." Two days later, Palmer & Hornbostel's site supervisor, David L. Wright, wrote to them on 18 October disputing Reilly's claims, stating that the reason the Sunday school interiors were not complete was because the roof was still incomplete – slate and copper had not yet been delivered to the building site (RSCA, file 11). Wright's comments became part of the official record in Palmer & Hornbostel's correspondence when they wrote to Reilly on 19 October stating that the delay in plaster work was because the roof was not finished and that in addition "we do not think that you have been delayed to any great extent for lack of details" (RSCA, file 14). Later the same month, Reilly complained to Palmer & Hornbostel that their slowness to supply drawings for the wood paneling in the main auditorium of the synagogue held up production of those elements by the Batavia & New York Wood Working Company by over two months (RSCA, file 5, 31 Oct. 1906).

Ultimately, it didn't matter that the wood paneling for the auditorium was not completed until 1907 since the Guastavino dome itself was not finished until mid-December of 1906. As work on the synagogue dragged on into summer 1907, the trustees of Rodef Shalom underlined the financial loss they suffered due to delays and "the lack of progress and the apparent indifference" of the general contractor (RSCA, file 8, L. J. Affelder to Palmer & Hornbostel, 8 May 1907). These complaints were passed on to Reilly by Palmer & Hornbostel, who wrote on 13 May 1907 that "there is no question but what you have shown lack of interest in this building and have not pushed it as it should have been done in face of requests to push matters" (RSCA, file 8). In his defense, Reilly pointed out that: "It would be a hard matter to expect to have this building completed in any reasonable time wherein the owners continued making changes until within a very few days past" (RSCA, file 8, 15 May 1907).

If the building committee and trustees of Rodef Shalom ran out of patience with Reilly in May 1907, Reilly could hardly be held responsible for the slowness of sub-contractors who themselves were held up for reasons beyond their control. The wood paneling for the auditorium produced by Batavia & New York Wood Working, for example, was only shipped to Pittsburgh in 1907 and was lost in transit on the railways around the beginning of May (RSCA, file 5, C. H. Honeck to D. F. Wright, 7 May 1907). It took several weeks to track down the railway cars.

3.2 *Changes and errors*

Changes to the design were of two types: those requested by the client and those required because the architect had not anticipated certain needs. The client made a number of requests for changes during the course of construction, starting with a proposal sent to the contractor for an extension to the organ loft in the main auditorium, which involved changing the specifications for steel structural elements. The new cost estimate supplied by Reilly needed to be approved by the architects before the additional expenses could be added to the project budget.

In a number of instances, it becomes clear that Palmer & Hornbostel had not anticipated needed space for heating and ventilating systems. On 19 April 1906, the building committee approved changes to the basement of the Sunday school wing to install heating and ventilating equipment. Reilly noted that additional excavation and construction were required to accommodate the chimney flue for the basement boiler, a change that Reilly requested on 25 April and was still not approved by the architects by 10 May, at which time Reilly expressed his concern that "changes are causing considerable annoyance and delay, as each time it is several days and weeks before these little matters are decided …" (RSCA, file 11).

Errors in drawings of relatively minor parts of the building caused significant delays. With the Sunday school building largely complete, furring of the interior wall partitions was suspended because the location of heating ducts had not been included on the initial drawings. As Palmer & Hornbostel wrote confidentially to their on-site representative on 13 September 1906, "this furring is the result of not having the heating plans decided upon when Reilly got the contract" (RSCA, file 11). The problem was still not resolved on 27 September when Reilly wrote to the architects expressing his "anxiety" about the situation (RSCA, file 11). It is clear that Palmer & Hornbostel's on-site representative did not have authority to resolve even minor problems that impacted the cost of the project and for which Reilly would bill in addition to his contract.

Even more serious, it became clear in December 1906 (after the dome was complete) that excavation below the auditorium was necessary to accommodate heating equipment. In a confidential letter to the building committee, Palmer & Hornbostel confessed that "this was originally in the contract but was taken out as it was thought unnecessary" (RSCA, file 11, Palmer & Hornbostel to N. Spear, 19 Dec. 1906). The question of what to do under the auditorium dragged into mid-January 1907, at which time Hornbostel appeared in Pittsburgh and ordered that installation of floor beams be stopped until the problem was resolved. It was determined that discrepancies between the site survey and the architects' drawings were the cause of the mistake and it was clear to the building committee, that "we consider this an error of the architect" (RSCA, file 8, I. Frank to Palmer & Hornbostel, 15 Jan. 1907).

Reilly chaffed at the hierarchy, in which the contract required approval by the architect of every minor change before the contractor could proceed. Since the architect mediated between the contractor and the client, Reilly was required to wait for Palmer & Hornbostel and the building committee to make decisions involving additional expenses. It could take weeks before a clear resolution allowed Reilly to proceed, precious time as the finish date loomed on the horizon. Reilly was an expert who had a well-earned sense of his own competence, as revealed in correspondence with Palmer & Hornbostel when he stated that "I have tried to be fair in all my dealings and will continue to do so but it is rather annoying to be nagged at all the time about these little items" (RSCA, file 11, 10 May 1906). The architects' sense of their own competence and key role in the building process is revealed when, the day after Reilly sent the above letter, Palmer & Hornbostel forwarded it to the building committee with their own cover letter stating that "We are much surprised at the communication from Mr. Reilly and cannot say that we are altogether pleased with its character and shall take steps to express our displeasure to him" (RSCA, file 11, Palmer & Hornbostel to M. Aaron, 11 May 1906). Palmer & Hornbostel thus shaped the building committee's opinion of Reilly's work and attitude throughout the construction process. Reilly's irritation at Palmer & Hornbostel's meddling in small changes was due in part to his expert understanding of what needed to be done to resolve issues as they emerged in the course of construction, but also because he was required to keep separate accounting for material and labor expended on what was defined in his contract, distinct from material and labor expended in making changes (RSCA, file 11, Reilly to Palmer & Hornbostel, 26 May 1906).

3.3 *Perth Amboy terra cotta*

As work progressed on foundations, Reilly requested detailed drawings of terra cotta elements to be executed by the Perth Amboy Terra Cotta Company of New Jersey. The question of responsibility for the production of detailed drawings of these exterior components emerged immediately. It was initially Reilly's understanding that shop drawings were to be generated by Perth Amboy and approved by the architects before their fabrication (RSCA, file 5, Reilly to Palmer & Hornbostel, 20 Mar. 1906), while Perth Amboy denied this to be the case stating in a letter to Reilly (that he passed on to the architects) that they "never agreed with Palmer & Hornbostel to make details for terra cotta work" (RSCA, file 5, T. Tait to Reilly, 28 Mar. 1906). Palmer & Hornbostel subsequently blamed Perth Amboy for not supplying detailed drawings of ornaments for their approval, thus delaying construction (RSCA, file 5, 2 Apr. 1906).

In late March-early April 1906, working drawings for the decorative terra cotta arch over the main entrance were produced by Perth Amboy and sent to Reilly who sent them on to the architects (Figure 1) (RSCA, file 5, W. C. Hall to Reilly, 30 Mar. 1906). At Palmer & Hornbostel's New York office, the young architect Samuel E. Plonsky sent instructions on polychrome terra cotta ornaments for Rodef Shalom to Perth Amboy on 28 April, indicating that details for the main entrance arch and dome would be sent later – a clear indication that production of terra cotta was held up by the architects. Palmer & Hornbostel acknowledged as much in a letter to Perth Amboy on 11 May stating that "we hereby relieve you from responsibility for delays in connection with delivering the polychrome work" and saying that they were still in the process of preparing drawings (RSCA, file 11). Perth Amboy responded a day later that they were still awaiting drawings for all the polychrome terra cotta (RSCA, file 5, Reilly to Palmer & Hornbostel, 12 May 1906).

Figure 4. Rodef Shalom Synagogue. Terra cotta over main entrance. Photo by author.

On 15 May – four months before construction of the synagogue was to be completed – Perth Amboy wrote to the architects saying that models were ready to be inspected for the key to the large arch over the main entrance, and for the coping and bed mouldings that would define the base of the main synagogue building.

Significantly, it was Reilly who sub-contracted with Perth Amboy and was thus responsible for paying for their work. It is clear that Palmer & Hornbostel regarded the terra cotta ornaments to be elements that required their special discernment to judge whether the models fabricated by Perth Amboy met their aesthetic requirements. Consequently, it was the architects rather than Reilly who dealt directly with the terra cotta manufacturer. Production of terra cotta was well underway when on 23 June, Perth Amboy sent photographs of full-scale models of mouldings to the architects for their approval – at a point after Reilly had suspended masonry work at Rodef Shalom because of the need for terra cotta elements. Photography was used on a number of subsequent occasions in the production of terra cotta for Rodef Shalom, allowing the architects to judge and approve components without needing to travel by train from Penn Station at 34th Street in Manhattan to the Perth Amboy factory in New Jersey.

Since the exterior masonry walls of the synagogue were being built at top speed before all the terra cotta components had been fabricated, Reilly left gaps to insert pieces as they arrived on site. On 2 July 1906 he wrote to Palmer & Hornbostel complaining that the terra cotta elements didn't match with the drawings of the building and that the architects' on-site representative had not provided proper guidance during initial construction.

The degree to which the terra cotta fabrication process and the architects' part in not completing drawings and approving models in time slowed down the construction of Rodef Shalom and forced Reilly to break his contract with the congregation is apparent from the correspondence. On 13 September 1906, around the date the synagogue was supposed to be finished, Perth Amboy wrote to Palmer & Hornbostel once again requesting details for polychrome elements. Perth Amboy was still fabricating components in November 1906 when they wrote to the architects indicating that they could visit the factory in New Jersey on 13 November to inspect models (RSCA, file 5, T. Tait to Palmer & Hornbostel, 8 Nov. 1906).

Given the delay in the production of the terra cotta elements for the synagogue, Reilly decided he was within his rights to withhold full payment to Perth Amboy and expressed extreme displeasure with their work. On 11 April 1907, Perth Amboy requested full payment for completed terra cotta; of the $20,360.00 contract, over half – $10,934.90 – was outstanding at that time. Reilly was unequivocal in his assessment: "I have a contract with the Perth Amboy Terra Cotta Company and that Company utterly failed to live up to the terms of their contract with me" (RSCA, file 11, Reilly to Palmer & Hornbostel, 1 July 1907). Reilly explained to Atlantic Terra Cotta (the successor firm to Perth Amboy) that he had incurred $303.82 in costs cutting out temporary brickwork and another $14,350.00 because they were 287 days late in completing their work (at a rate of $50 per day in damages) (RSCA, file 11, 3 July 1907).

3.4 *Guastavino*

Like the relationship between Reilly, Palmer & Hornbostel and Perth Amboy Terra Cotta, the relationship between Reilly, Palmer & Hornbostel and Guastavino reveals a three-way interaction that put the general contractor at a clear disadvantage in determining how to proceed with the execution of the building.

With construction of the foundations underway, Guastavino produced estimates of the weight of the dome which showed a need to integrate steel reinforcing bars into the auditorium walls (RSCA, file 5, Guastavino to Reilly, 26 Mar. 1906). The contract with Guastavino was signed on 31 March 1906, immediately after which Reilly requested that Palmer & Horbostel send a complete set of drawings to Guastavino so they could begin designing the dome (RSCA, file 5, Reilly to Palmer & Hornbostel, 2 Apr. 1906).

By 11 May, Reilly had a more detailed sense of the dome construction and wrote to Palmer & Hornbostel expressing misgivings about the supporting structures, asking them to "look more carefully into the question." Once again, a clear clash in which the contractor's expertise in construction conflicted with the architects, who responded to Reilly the following day stating that "we have had our engineers figure these piers very carefully …" (RSCA, file 11, Palmer & Hornbostel to Reilly, 12 May 1906). Reilly was not satisfied with this answer, re-stating his concerns about the load-bearing capacity of the brick piers on 14 May.

On 20 July 1906, Reilly claimed still not to have received plans for the dome from Guastavino. By this stage, the auditorium walls were largely complete and on 1 August, Reilly wrote to Palmer & Hornbostel stating that work was at a standstill and that the architects and Guastavino were urgently needed in Pittsburgh to discuss the auditorium windows, the metal reinforcing that Guastavino specified for the upper part of the walls, and the corbels that needed to be built into the walls to support the vault. By this point, Guastavino claimed to have been in Pittsburgh twice already to discuss the synagogue dome and stated he would arrive in Pittsburgh on 6 August to begin erecting scaffolding – a month before Reilly was contracted to complete the building.

Guastavino's dome was the most consequential subcontract in the construction of Rodef Shalom, and it seems from Reilly's correspondence with Palmer & Hornbostel that the schedule of construction was ultimately contingent on Guastavino's planning. In August 1906, within a month of the stipulated completion date, Reilly wrote letter after letter to Palmer & Hornbostel complaining about Guastavino, whose tone in written correspondence he described as "offensive and uncalled for" (RSCA, file 5, Reilly to Palmer & Hornbostel, 4 Aug. 1906). Lack of information about the details of the dome construction caused major delays for Reilly. On 4 August, Guastavino sent drawings to Palmer & Hornbostel and was still waiting on 16 August to hear back from the architects before he could build centering for the dome. The urgency of the situation is reflected in Reilly's correspondence, writing to Palmer & Hornbostel that: "This additional work was not shown on the plans and no explanation was given that any additional work would be required, although I pressed very hard for information on the question of expense in changing … to the Guastavino system …" (RSCA, file 11, Reilly to Palmer & Hornbostel, 24 Aug. 1906).

Construction of the dome only started on 5 September 1906. On 1 October, Guastavino wrote to Palmer & Hornbostel alleging that Reilly still had not built steel reinforcing bands into the upper parts of the brick walls of the auditorium, preventing him from beginning the dome. The same day, Reilly pointed out in a letter to Palmer & Hornbostel that Guastavino's "way of doing business [has] been mysterious from the start and have caused considerable misunderstandings. They have not furnished me with any drawings showing what corbelling they required or the way their steel bands were to be built in …" (RSCA, file 11). Reilly shifted responsibility for the construction of the upper walls of the synagogue auditorium to Guastavino, stating in a letter that "The brick work to which you refer, around your iron bands, was to have been built up by you" and indicating that the lack of progress on the dome during the last three weeks of September was entirely Guastavino's fault (RSCA, file 14, Reilly to Guastavino, 1 Oct. 1906). Palmer & Hornbostel in turn wrote to Reilly on 4 October shifting responsibility for the dome onto the two contractors, stating that "we do not feel that we should be mixed up in any way in this matter" (RSCA, file 11).

The dome over the auditorium of Rodef Shalom Synagogue was built in a period of just over two months. By 18 October, Guastavino requested a first payment of $3,995.00. On 17 November, Guastavino complained that he had only received $4,465.00 in payments for a total of $17,000.00 of work completed by that time. Aiming to complete the dome by 28 November, work on the tile vault dragged on until 16 December and cost a total of $19,620.00. Work still needed to be completed plastering the interior, waterproofing the exterior, installing roof tiles, terra cotta ribs, and the metal skylight.

Guastavino was a prima donna of the construction industry and the dome of Rodef Shalom was an especially significant commission. The schedule for completing the synagogue was contingent on Guastavino, since no other firm could execute the work. Ultimately, the dome would figure in Guastavino's promotional materials as the largest such vault built by the firm at the time of its completion (Figure 1) (Ochsendorf, 2010, 96). Little did it matter that the structure was completed behind schedule. Guastavino preferred to work with prominent architects who would specify his technique; no account needed to be taken, apparently, of general contractors, who were compelled to accommodate Guastavino's methods and timetable.

4 CONCLUSION

The trustees of Rodef Shalom took possession of the new synagogue on 31 August 1907. The first service was held on 6 September in a building still not complete and a year behind schedule. In late August, an agreement that work be finished by 1 November of that year had been hammered out by the architects, the building committee and the general contractor; in early September, the lawyer for Rodef Shalom, Joseph Stadtfeld wrote to Reilly claiming damages in the amount of $36,500 for failure to complete the building on time – at a rate of $100 per day for a full year (RSCA, file 8, 17 Sept. 1907). Given the preceding analysis, the claim was unreasonable and the timing of Statfeld's letter a slap in the face to Reilly. Palmer & Hornbostel themselves pointed out that some 22 changes requested by the building committee were the cause of delays, an argument Stadtfeld flatly rejected.

Press coverage of the dedication of Rodef Shalom celebrated the remarkable building without mentioning the difficulties encountered during construction. In the commemorative issue of the *Jewish Criterion* published on 12 September 1907, Palmer & Hornbostel are credited with the design and Guastavino published a full-page ad including a construction photo of the auditorium dome. No mention is made of Thomas Reilly. What the correspondence reveals is a process involving designers, builders and manufacturers distributed across at least five states with elements being fabricated and shipped hundreds of kilometers within very tight time frames. Reilly's ability to manage was hampered by many factors, including the architects' production of drawings well into the construction process, and changes to the design made after he signed

Figure 5. Rodef Shalom Synagogue. Advertisement for R. Guastavino, *Jewish Criterion* 25, no. 14 (12 Sept. 1907).

his contract with the building committee, not the least of which was the substitution of Guastavino's dome for a steel structure as specified in the original bid documents.

In early-20th-century Pittsburgh, constructing the Beaux-Arts building was a messy business. The inauguration of the synagogue marked the beginning of a lawsuit between Rodef Shalom and Thomas Reilly that would drag on for several years, while the completion of the building would ultimately be entrusted to another builder. Among the triumvirate that realized the splendid vision of a modern synagogue for Pittsburgh's Reformed Jewish congregation, the general contractor shouldered the greatest burden, took the greatest financial risk and had the least control over the process. Changes could be made at any point in the construction process by the architects or the building committee that Reilly was compelled to accommodate, each one adding greater complexity to his work. Guastavino and Perth Amboy Terra Cotta were ostensibly bound by contract to Reilly but were beholden in fact to Palmer & Hornbostel for the designs of the parts of the synagogue they executed. While authorship of Rodef Shalom ended up being shared by the architects and Guastavino, legal liability for the building was shouldered entirely by the general contractor.

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History of Construction Cultures – Mascarenhas-Mateus & Paula Pires (eds)

Industrialising timber craftsmanship: Early glulam within the traditional timber construction in Switzerland

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ABSTRACT: Early glue laminated timber in Switzerland was used for many functions: industrial but also regular buildings such as sport halls, cultural buildings and housing. Integration of the new practice was only achieved by involving existing traditional players. Contractors had to bring together a long-standing knowledge of local timber craftsmanship and the patented glulam technology. The paper traces the early onsite construction practice of glulam by looking at the handling of the contractor for both fields, the use of glulam for industrial one-room structures and for the use of large glulam elements in roofs of ordinary buildings. The licensed contractors developed methods for fast and flexible erection of the glulam parts. Key was the development of a constructional unit, the two girder halves with post and tie beams, that was fully joined flat on the ground and then, as an entity, lifted into place, using tripods or other movable lifting devices.

1 INTRODUCTION

1.1 *Early glulam in Switzerland*

Shortly after the German master carpenter Otto Hetzer was granted the first patent for glue-laminated timber in 1906 (Hetzer 1906; SBB 1911), the technology arrived in Switzerland with an immediate impact (Müller 1998). The young engineering office Terner & Chopard had acquired the Hetzer patent in 1908 and the exclusive right in Switzerland (Rinke 2015). A few years later, in 1912, they founded, together with other partners, an independent corporation which then held the patent, and which was dedicated to managing the design and production of all glulam structures in Switzerland (Kaegi 1936). Behind the Schweizerische AG für Hetzer'sche Holzbauweisen (SHH), the Swiss Corporation for Hetzer Construction, was a consortium of licensed carpenter contractors. These contractors, mostly well established and well experienced in timber construction, produced the glulam members and carried out the construction on site. This form of organization guaranteed a strict high-quality assurance based on consistent know-how and the application of the latest technical and scientific developments (Chopard 1936).

Nine years after the very first application of glulam in Switzerland, the SHH published in 1917 a brochure celebrating its achievements (the first published in 1913). Among the ca. 200 projects they list are many particularly representative buildings which clearly demonstrates the broad and representative use of the new technology in Switzerland (Table 1). Among those mentioned, there are of course many industrial buildings (41%) such as factories or warehouses, as the use of timber as a structural building material at that time was limited to smaller and mostly agricultural buildings.

Table 1. Overview of functions of early glulam projects* (1908–17).

Function	Number	
Industry + agricultural	41	34%
Sport halls	24	20%
Infrastructure	16	13%
Public (admin, education, hospitals)	14	12%
Culture	12	10%
Housing	10	8%
Churches	2	2%

*listed in the SHH catalogue (ca. 200 projects in total).

The large majority of the buildings mentioned were, however, regular building constructions such as, sport halls (20%), public (12%), or cultural buildings (10%) and housing (8%). This first placing of glulam in the actually built context shows, in the first instance, that glulam was used throughout Switzerland and for all kinds of buildings, commissioned by all sorts of clients.

The use of glulam was in most cases a consequence of its competitive price (Kersten 1921), that is for practical reasons. Rarely was it meant to be seen or

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intentionally exposed when it was chosen. Glulam rarely had to mean something beyond its technical functionality. Rare exceptions are its use for the Swiss National Exhibition in Berne 1914 (Haddadi & Rinke 2020) and a few railway platform roofs (e.g. Interlaken, Visp or Gossau). It was only then for the large public show of Swiss fabrication capacities that glulam was dubbed a true national material.

On the one hand, a major influence for its early acceptance can certainly be attributed to the commitment of professional associations (SIA), material research (EMPA) or the early commissioning by the Swiss railway authorities (Rinke & Haddadi 2018). On the other hand, integration of the new practice was only achieved by involving existing traditional players who were responsible for the actual production on site. The licensed contractors had to bring together a long-standing knowledge of local timber craftsmanship and the patented glulam technology. As the glulam technology was penetrating one of the most traditional fields of the construction sector, its introduction process affected many participants of different qualifications, interests and intentions. The early years of glulam in Switzerland saw difficult economic periods before, during and after World War One, together with regular, in some cases heavy, strikes by the carpenters (up to several months like in 1920).

1.2 *Practices and limits*

Although it was right from its origins a substitute material, glulam was not a disruptive technology destined to replace all sorts of existing timber construction techniques in a short period of time. It also did not impose a new constructional thinking, new structural forms or constructional processes beyond its very fabrication procedure. Glulam was an immediate alternative for large scale structures typically constructed in steel. Here, the general setting was given with clearly distinguishable hierarchical components: two main girder halves formed an arch with articulated hinges and (mostly) with widest sections in the corners (or in the halves' centre). In these large-scale structures, glulam was often limited to these main girders. The purlins spanning between them, together with the rafters forming the actual roof area were of simple solid wood. If the distance between the girders was extraordinarily high (mostly exceeding 5m), articulated glulam purlins were used, sometimes also artistically curved rafters, like in the case of the riding hall in St Moritz (Rinke & Haddadi 2018). Due to their large-scale nature and mostly one-room functionality, the glulam main structure was clearly separated from all other parts of the building and thus did not need to be integrated with other construction parts or materials. The overall layout, component forms and details all resembled the highly typological steel structures, a well-known standard practice at that time (Haddadi & Rinke 2019).

But glulam was also used for much smaller applications, mostly in roof structures and low-rise urban developments. Here, it was a substitute not of the entire structural framework but of single components. They vividly demonstrate Hetzer's primary idea of his new system: a single generically defined and industrially fabricated glulam element replacing the traditional set of roof members. The small-scale structures, in particular, demonstrate how the introduction of glulam was not a radical shift but rather a transitional process with a dominant driver of functionality and a traditional external building appearance. The new, mostly large-format construction elements were used specifically for those areas of the building where the limits of the conventional were to be exceeded, i.e. above all for wide-span roof constructions, or where the space in some parts of the building was to be kept free from columns and struts.

Although the new construction method had a high standard of quality in its fabrication, there were hardly any standards or an established practice for its actual construction on site. Assembly and fastening, both in combination with other materials and between glulam and small-format timbers, had to be figured out in the first practical applications. Using the scale of steel girders handled by a traditionally run carpentry practice crossed lines of existing responsibilities and competences of various players. The coexistence of timber technologies with different stages of industrialization brought new aspects of organization in design and construction. The actual preparation, pre-fabrication, putting-in-place and on-site fabrication will be discussed in the following sections of this paper. First, the construction practice and industrialized processes with large-scale structures and, subsequently, comparison of this practice with small-scale application in roof structures. Finally, the developments and tendencies will be placed in a wider context.

2 CONSTRUCTING LARGE-SCALE STRUCTURES

2.1 *Procedures for standard hall constructions*

Most of the large-scale one-room structures were of the same type and were typically used for factories or warehouses. They consisted of two half-girders forming a three-hinged arch with one "hinge" at each footing and one at the top where both parts met. Often, when the large half-girders exceeded regular transportation sizes, they were segmented and, consequently, featured a construction joint, in many cases below the highest curvature and just above the lower "straight" part. But the size of these large structural elements also exceeded the manual handling capacities of the carpenters. For regular timber structures, construction wood was delivered and stored on site. It was then available in different dimensions as specified in the construction drawings of the architect, sometimes together with additional shop drawings from the contractor. The individual pieces were lengthened and prepared with all connections, then eventually

Figure 1. Construction process of the girders of the Schweizerische Eternit-Werke in Niederurnen, ca. 1912 (Schw. AG für Hetzer'sche Holzb1913).

placed in their definite location. Most of these regular construction members featured traditional wood working joints such as mortise and tenon or half lap joints. As the connection of the large glulam members, however, were also scaled, they were not fabricated on site but, together with the elements, prepared in the workshop. The joint between the two elements of each girder half was done as a lapped scarf joint together with steel plates from both sides and bolts. The connection at the top between the two girder halves was almost always done by placing the elements against a central post using single step joints together with steel bands tying girder and post together. This mix of connection types, traditional and mechanical, was typical at the beginning of glulam construction (Rinke & Haddadi 2018).

The top hinge could have been constructed with an engineered steel hinge as was done in a few other cases (Rinke 2019) ensuring a perfect mechanical functioning at that point. For contemporary large-scale steel structures both halves of the three-hinged arch were lifted and met against each other through such a hinge at the vertex. The post, however, was not simply a remnant of traditional carpentry but was a key element to form, together with the tie beams, a stable triangular upper part of the girder for the erection process. On site, this part was prepared flat on the ground, as Figure 1 shows: the two upper segments of the girder halves, connected with the post at the top and connected through a tie beam (consisting of two flat timbers placed on both sides of the glulam elements receiving the post at their centre). The tie beam was placed just above the girder joint, and sometimes a second tie beam was added just below the top hinge for extra stability. This upper tie beam also offered a practical suspension point for cables when this stable unit was then lifted, either through tripods and hoists or a crane. As the upper part was lifted into its final position, the lower parts of the girders were added by slotting them in between the steel plates which were already attached to the upper segment before the lifting. Using this procedure, the carpenter only needed ladders to place the bolts into the connection steel plates and to add further timbers longitudinally to keep the girder in place.

Figure 1 shows this erection process for the girders of a warehouse of the Swiss Eternit factories in Niederurnen. The contractor B. Zöllig from Arbon (Thurgau), one of the licensed glulam contractors, developed a movable lifting device for the repetitive erection of the girders. They placed the purpose-built timber crane on rails and shifted along the central longitudinal axis of the building so that all girders could be swiftly placed without scaffolding by very few skilled workers.

2.2 *Responsibilities and competences*

Zöllig was one of the largest and most experienced contractors in the consortium behind the SHH. He also played a leading role on its board (1917) and was a board member of the Swiss carpenter association (1915). He was involved in the construction works of the national exhibition in Bern in 1914 which in large part consisted of timber structures, all of which were meant to represent the craftsmanship and industrial capacity of Switzerland. Zöllig was in charge of Hall 3, a building exhibiting the construction industry and designed by the well-known local architect Otto Ingold (Ingold 1913). Apart from the extraordinary contractual agreement for the exhibition, according to which the contractor was the owner of the building renting it to the organizers for the period of the exhibition and was thus responsible for dismantling and transporting it from the site, his engagement here offers an extraordinary insight into the daily organization of the construction. The daily reports from the site manager Hagen in Bern to Zöllig in Arbon allow a better understanding of the organization and procedures behind the glulam practice. For Ingold's project, Zöllig proposed a structure with eight glulam semi-circular arches and six half-arches for the ridges and the annexes (Zöllig 1913a), each half spanning 11.50 m with a rising height of 12.55 m (SHH

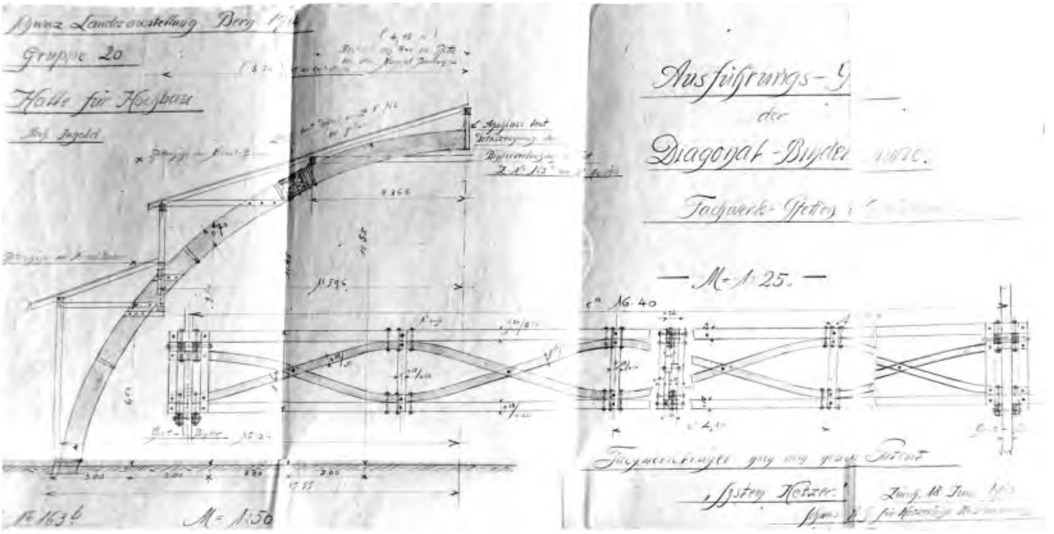

Figure 2. Shop drawing for the glulam elements of the diagonal girders, Hall 2, 1913 for the national exhibition in Bern 1914 Schweiz. AG für Hetzer'sche Holzbauw., SHH).

1913). For the entire timber works, Zöllig deployed 11 workers, most of them carpenters in permanent employment but also a few temporary local carpenters to support the works. Through the detailed descriptions in these reports we learn that dissatisfaction with wages was a recurring issue Zöllig and his workers had to resolve over and over.

The constructional detailing for the Bern girders was somewhat common but needed to be adapted. Again, for each half-arch a joint was used commensurate with its overall size and transportation constraints. These segments were first assembled on the ground and then lifted which is why the site joint between the two segments of each half-arch not only features a steel plate on each side but also steel u-profiles embracing both the top and bottom of the glulam section at this point.

Unlike the ordinary timbers the glulam segments could not be moved by the carpenters alone. For unloading these heavy parts, they normally used mechanical devices but also for their relocation, as the site manager explained in his progress report: "The girders could not be placed yet, because they have to be transported to the location where they will be placed. Tomorrow, Thursday morning, we will be able to start with this. We have taken care of unloading the girders ourselves, as we could not use the crane, which has an electric drive and was being repaired this morning (…)" (Zöllig 1913b). The most easily available lifting device was directly set up by the carpenters themselves, both for unloading and also for lifting in general: "This morning we loaded up, unloaded at the exhibition site, set up the tripod, assembled the ridge girders and pulled them up." Eight days later, all girders had been placed, relying on 11 carpenters on site. As several lifting devices were already set up, they were used to construct the walls.

As the scale of the glulam parts exceeded the capacity of the workers and required a thorough mechanical approach with a coordinated use of machines, the planning capacities of the contractor called for a systematic approach. In general, the scope of the licensed contractors was clearly limited to the fabrication of the glulam parts and the constructional work on site. They were sometimes commissioned as general contractors of a building, but mostly they were responsible for all timber works of which the glulam elements were only a small but important part. Zöllig, for example, took over all timber works for the complex dome construction of the SUVA office building in Lucerne just a few months after the exhibition in 1915 (Rinke 2017).

The design of the glulam structures fell to the license holder, in the beginning Terner & Chopard and later SHH. The contractors, with their growing experience and local networks, could propose a design, tender for projects or negotiate details alone; for large-scale projects where the structure was considered an essential part of the building, glulam was often a construction option from the beginning. All technical specifications, however, together with the shop drawings for the fabrication of all glulam parts were given by SHH (Figure 2). Interestingly, the design procedure was rather generic as the structural calculations or site specifications from SHH (or Terner & Chopard) never considered the specific site conditions, circumstances of the construction process or detailing of the site joints or footings. As usual, the structural calculation carried out by the engineering office was a standardized procedure similar to steel structures where, eventually, the material properties of glulam were incorporated for the actual dimensioning at the end. The regular steel stirrup securing the lamellas as a compound, the footing or the top hinge detailing was based on a standardized design approach.

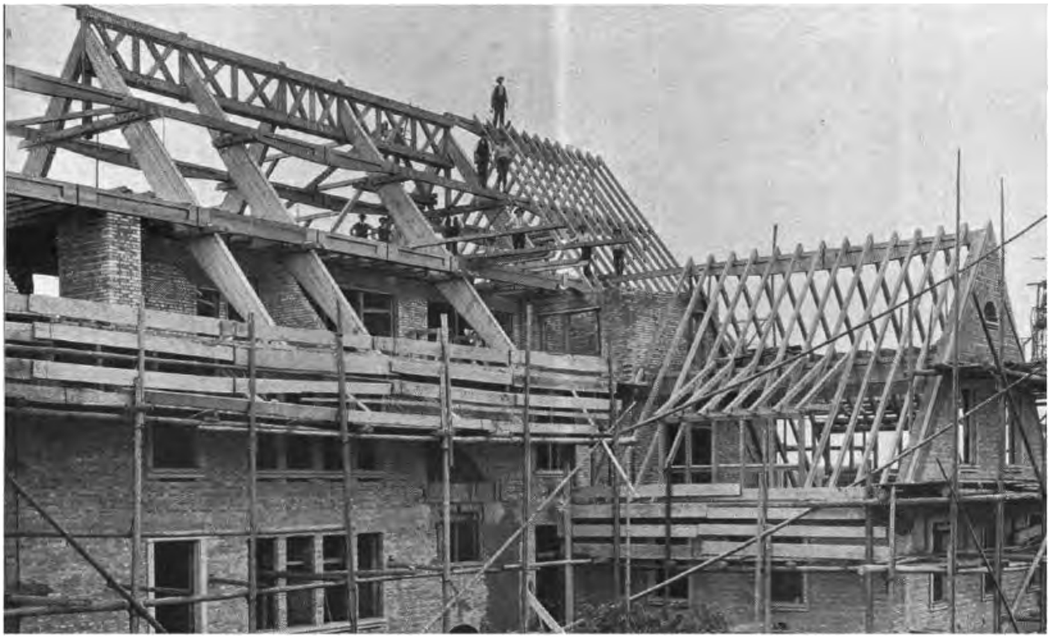

Figure 3. Carpenters on the construction site of the Catholic church in Romanshorn, 1911 (Church archive).

3 SMALL-SCALL APPLICATIONS WITHIN MIXED STRUCTURES

3.1 *Standardized girder application*

Another important field of glulam application was the use of large elements in roofs of ordinary buildings (Rinke & Haddadi 2020). Either they were used to accelerate or simplify the construction process, especially when the given structure was repetitive, or to reduce the number of constructional elements in the roof, such as posts and struts, to allow for more space and increased functionality. Here, the close coexistence of industrially fabricated and processed glulam components and ordinary traditional timber works within a one-roof structure demanded particular coordination of workers and building components. An interesting example of such a combination is the roof structure of the Swiss hospital for crippled children in Zurich, built in 1913 (today university hospital Balgrist, Figure 3). It was built by another licensed timber contractor, from Fietz und Leuthold. An important partner in glulam construction, Emil Fietz, was one of the founders and directors, and from 1909-15 of the Swiss carpenters' association and 1909–19 board member of the Swiss contractor's association (Fietz & Leuthold 1989).

The smaller building on the right has a roof of moderate size which does not need any girders between gables. But to not require any posts or other structural members, both the ordinary ridge and intermediate purlin were replaced by massive glulam beams, curved and straight in detailed execution respectively.

On the left, the larger roof structure of the main building reveals a greater complexity. Probably due to time pressure, the brick walls were already up to the roof level when the carpenters erected the roof, which created a much denser working space for them. The backmost part of the building features a roof similar to the aforementioned one on the right: between two girders span curved purlins to receive the regular rafters. The major roof structure in front consists of massive glulam girders which are placed with slightly varying spacings. Their positioning clearly reacts to the functional space inside the roof, as the room dimensions determined the place of the adjacent girder. Consequently, the purlins which span in between them are adjusted according to their span and load: curved or straight respectively.

The erection of the wide girders in the roof, however, seems to have been a fundamental problem, especially given the density of the given space. Based on the insights from the construction method of the repetitive girders from the larger one-room structures, such as the Eternit warehouse or the Bern exhibition, the actual procedure can also be traced for the given situation of the hospital roof in Zurich. Firstly, the complete closed girders were placed, which consist of both halves and two pairs of tie beams connecting them, together with the central post. They were most likely also first put flat on the ground of the roof level, put together and then lifted with tripod or with the crane which can be seen on the very right. Between these two closed girders, placed at each end of the roof of this main part of the building, a long truss was then placed spanning the entire length. The halves of the intermediate

Figure 4. Swiss hospital for crippled children in Zurich, 1913 (Schw. AG fürHetzer'sche Holzb. 1913).

girders were simply placed against this large-scale ridge beam from both sides resulting in girders which were open (without tie beams). The spatial complexity of manoeuvring full girder units was thus reduced through hierarchy using primary girders and larger purlins.

Another case exemplifies the application of girder units which was successfully used for the quick erection of repetitive girders in industrial buildings. Also, for the church in Romanshorn (Gaudy 1913), glulam girders were used to simplify the roof construction, particularly for the given geometry of a raised and curved church ceiling that did not allow straight horizontal tie beams between the girder footings. Figure 4 shows the construction works of the glulam girders shortly after they were placed. Again, all girders are formed by a pair of two identical halves which are connected through a pair of tie beams and a short a par at the very top, probably to hook the cables for the lifting. As there was no crane available on site, the carpenters used tripods which can be seen in the left of the photo with the ladder leaning against it.

3.2 *Responsibilities and competences*

The case of the roof construction for the Catholic church in Romanshorn also gives insight into the actual demarcation of responsibilities between the actors. For roof structures of ordinary buildings, glulam came mostly only during the tendering process as one of the licensed contractors would propose this as an alternative to the architect's plans which was based on common timber roof typologies. Here, architect Adolf Gaudy proposed a roof structure without glulam as it was open to all those contractors who were not licensed for the use of glulam. Gaudy was familiar with glulam construction as he used it for several of his projects at that time. Terner & Chopard were commissioned with the glulam girders that were the preferred option for the definite construction. Whether Gaudy reached out to them (SHH was only founded the following year) for a glulam option or how they came together with a contractor is not known because of missing planning documents. Eventually, the local contractor Wallisser from Romanshorn was chosen for the timber works which was unusual as they were not a licensed glulam contractor. According to their contract, Terner & Chopard was in charge of "delivery, preparation and erection of the standard girders 'System Hetzer' over the nave and transept made of best, air-dry spruce wood, statically calculated (…) incl. all steel components such as tie rods, stirrups, screws, bolts, etc. as well as the associated timber parts such as central posts and all tie beams including all necessary scaffolding" (Terner & Chopard 1910). Most likely they subcontracted Zöllig, the regional licensed contractor, who would have finished his work as it was documented by the client in the photo (Figure 4), so that contractor could take over for the rest of the timber works. For the Romanshorn church roof, the contractual practice was inversed: Whereas normally the timber contractor had a contractual relationship with the client and then reached out to Terner & Chopard, or later SHH, the latter were here subcontracting their regional licensee.

4 CONCLUSIONS

Already the early years of glulam construction in Switzerland saw a broad and representative use of the new technology. Next to the many industrial buildings, such as factories or warehouses, it was also used for regular buildings such as sport halls, public and cultural buildings and housing. Based on the rather generic design by the patent holders, engineers Terner & Chopard or later the SHH, the licensed contractors developed construction methods for a secure, fast and flexible erection of the glulam parts. A key element was the development of a constructional unit, the two girder halves with post and tie beams, that were fully joined flat on the ground and then, as an entity, lifted into place, using tripods or other movable lifting devices.

This process had to be strictly organized from off-site fabrication, delivery and positioning, since the scale and uniqueness of the component did not see the worker on site as a constructing craftsman but as a practical assembler: these large-scale timbers were not crafted and fitted but systematized and assembled according to the kit.

The constructional details grew with the scale but stayed in that period between craftsmanship and mechanical steel parts like the bearings or the site joints. Glulam was, according to the people conceptualizing and using it, a substitution for steel and concrete because it was competitive and broadly accepted early on. But although forms and structural concepts resemble the materials it was pushed to replace, the constructional processes were not. The putting-in-place was, like the connections, a convergence of tradition and technological: the material knowledge in the craftsmanship of the carpenters and a process-orientation through the fabrication regime of a new timber industry.

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History of Construction Cultures – Mascarenhas-Mateus & Paula Pires (eds)

Luigi Santarella: Reinforced concrete design culture through the technical literature

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ABSTRACT: Luigi Santarella is considered to have been one of the most important Italian theorists in the field of reinforced concrete yet his professional activity is still completely ignored by the critical literature. The structures designed by Santarella – concrete frames, bridges, canopies for stadiums and roofing systems with innovative trusses – and built by contractors specializing in reinforced concrete construction represent the pragmatic experimental field of application of the building principles set out in his widespread theoretical books. The relationship between the building principles and the structural solutions analysed in his texts with his designed and realized structures, in the wider context of the design and construction culture of the time, will shed light on the interaction between the design process and construction instances as well as on the mechanics related to their dissemination through the technical literature.

1 INTRODUCTION

The Italian engineer, theorist and structural designer Luigi Santarella (Corato, June, 12 1886 – Milan, September 7, 1935) is considered one of the pioneers of the experimentation and application of reinforced concrete in Italy: yet although not completely ignored, his career and professional activities are still unexplored by the academic literature (Bologna 2015). And there has been little investigation into his life and accomplishments over the years compared to those of other Italian structural designers of his time, such as Attilio Muggia, Gustavo Colonnetti or Pier Luigi Nervi.

Having graduated from the Politecnico di Milano in 1910 with a degree in civil engineering, Santarella continued to be linked with the Milanese university until 1935, the year of his premature death. He was both a lecturer and director of the *School of Specialization for Reinforced Concrete Construction* promoted by the Fratelli Pesenti Foundation, one of the six Schools of Advanced Studies in the various branches of engineering, added to the five-year study course of the Regio Politecnico di Milano in 1926. In addition to teaching, he had also developed intense professional activities in the early 1920s, along with the dissemination of technical and scientific knowledge: both theory and practice represented two significant parallel and closely interrelated paths for the engineer.

Thanks to the widespread distribution of his books by the Milanese publishing house Ulrico Hoepli, Santarella established his reputation from 1923 onwards for his translation into Italian of volumes such as *Theory and Practice of Reinforced Concrete* [*Teoria e pratica del cemento armato*] by Emil Mörsch (Mörsch 1923) and *The Science of Construction* [*La scienza delle costruzioni*] by Heinrich Müller-Breslau (Müller-Breslau 1927). Santarella gradually developed his own personal and distinctive method of spreading technical knowledge through the publication of numerous articles, books and manuals on the theory and experiments carried out on reinforced concrete structures at the time. His *Handbook of Reinforced Concrete* [*Prontuario del cemento armato*], published by Hoepli, became a real best seller over the years and is still in print today. Having been progressively updated, it is now in its thirty-eighth edition and continues to contribute to the training of entire generations of architects and engineers.

The reason for the success of his books lies in the author's acknowledged ability to present and explain the results of research and experiments carried out on reinforced concrete, clearly and concisely, using drawings and construction diagrams but also numerous photographs of building sites and the respective works. The many reviews published from 1924 onwards in the most popular trade journals of the time, both in Italy and abroad – such as *Il Monitore Tecnico*,*L'industria italiana del cemento*, *Engineering* and *La Technique des Travaux* – bear valuable witness to this success. Santarella knew how to make complex principles of calculus and implementation of material accessible to architects and other operators in the construction

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industry of the time who lacked the scientific preparation of engineers, publishing real theoretical-practical treatises on the subject. His books are richly illustrated: they contain numerous written recommendations, as well as design suggestions and theoretical explanations but, above all, explore matters of a constructive nature, providing examples of structural dimensioning calculations developed and commented on.

For example, in the first edition of *Italian Bridges in reinforced concrete* [*Ponti italiani in cemento armato*], published in 1924 with Eugenio Miozzi, another great Italian engineer of the time, Santarella's intention was to compile and circulate the most important projects for the reconstruction of the "glorious bridges sacrificed to war" (Santarella & Miozzi, letter to Mussolini, April 27, 1924a) built in Italy in recent years: with 350 pictures appearing in the text and 90 design boards published in the Atlas, design experts and site technicians alike were able to make use of numerous examples, described and illustrated by detailed executive drawings, without resorting to the complex calculus formulas that characterised most of the technical literature in the sector (Miozzi, letter to Hoepli, June 23, 1922).

According to Santarella, design and building site practice and the theory defined by the emerging discipline of building technology represented an indivisible whole. This approach allowed him to pursue a veritable action of scientific propaganda at the national level, disseminating through his publication's pictures of projects – many of which he had developed himself – and the most significant and daring (for the time) reinforced concrete constructions designed by engineers and implemented by Italian construction companies all over Italy.

2 BOOKS AS OPERATIVE TOOLS: A NEW RELATIONSHIP BETWEEN TECHNICAL TEXT AND IMAGE

Santarella and his books became part of a publishing current that had already been clearly defined by Hoepli, the so-called "Technical Library". Examples of this type of publication include the very popular *Manual for the Civil and Industrial Engineer* [*Manuale dell'ingegnere civile e industriale*] by Giuseppe Colombo (Colombo 1877) and *Concrete and Reinforced Concrete Constructions* [*Le costruzioni in calcestruzzo ed in cemento armato*] by Giuseppe Vacchelli (Vacchelli 1899), both of which were also used to support the teaching programmes of technical schools and aimed particularly at so-called "practical engineers" (Decleva 2001), whose activities mainly focused on building site practice. Unlike these books dedicated to structural dimensioning, Santarella's works establish a very different relationship between texts and pictures, producing real illustrated atlases.

Technical manuals represented one of Hoepli's main commercial lines of business. Santarella fitted into it perfectly, innovating the communication system used to deal with complex issues, such as structural dimensioning and its implementation in cementitious structures, accompanying the formulas with descriptive texts as well as drawings of construction details, photographs of building site machinery and the analyzed structures (Santarella 1932). In 1926, Santarella published the first edition of *Reinforced Concrete in Civil and Industrial Construction* [*Il cemento armato nelle costruzioni civili ed industriali*], in two volumes (Santarella 1926). Divided into three parts, with 640 illustrated boards in the text and an atlas with 64 construction drawings, this book also aimed at highlighting the progress in reinforced concrete usage in Italy as well as providing builders and designers with a wealth of illustrative materials on significant examples. The innovation of Santarella's book lies precisely in the part dedicated to the so-called Monographs, illustrated technical data sheets of 39 works that he selected, accompanied by numerous construction details. Among the over 600 images contained, Santarella also included some pictures of his projects, such as the 1920 long span roof of the Fossati garage in Biella, in the work. The same photographs of his structures were simultaneously published in the pages of the most popular technical journals of the time along with projects by other engineers who were destined for greater critical success, such as the airship hangars built in Parma in 1918 and the Fiat Lingotto factory in Turin in 1922: structures built by the Ditta Giovanni Porcheddu, the North Italian licensee of the Hennebique patent (San Nicolò 1925).

The distribution of Santarella's book in Italy is indicative of the success of a communicative language that was unheard of at the time, extremely effective and destined to have far-reaching repercussions on professional practice. By 1927, the book was already in its second edition, completely renewed and expanded, described as the most complete and reliable volume on the subject on the Italian book market (*Atti del sindacato provinciale fascista ingegneri di Milano*, June 1927, 47). In the second edition Monographs, Santarella describes and publishes some pictures of other saw-tooth roofing which he had designed for the wool mill Trabaldo in Pianceri – near Biella –, the cotton mill Val Seriana in Gazzaniga – near Bergamo – and for the silk factory Seterie Stampate Tondani plant in Portichetto – near Como (Santarella 1927).

Two years later, and once again with Hoepli, Santarella published the first edition of the *Handbook of Reinforced Concrete* [*Prontuario del cemento armato*] (Santarella 1929d).The book's long subtitle – *Data and formulas to speed up the study and control of schematic design in the most common structures* – clearly defines its aims: to serve as a valuable educational tool for architects and engineers but also a pragmatic operational tool for professional practice. Santarella showed, once again, his constant interest both in providing the reader with theoretical contributions and in illustrating the main results of their application. This reflected a process of transferral of scientific and technical knowledge capable of considering both theoretical aspects and professional and building site practice. Again, the diagrams and graphic elaborations – drawn by Santarella and re-elaborated by the publisher – aimed to highlight the technical progress made in the use of reinforced concrete in Italy, presenting solutions and design suggestions that were as bold as they were economically and constructively appreciable. “Optimization” was the key word often used by Santarella, with reference to both the construction materials used and the time dedicated to the design and construction of the building.

Santarella proved his design and educational skills to the academic and professional community at the time with these publications, enabling designer-readers to increase their creative capacity and stimulating their constructive intuition with a vast repertoire of dimensioned, calculated and built examples from which to draw inspiration. This publishing strategy turned out equally successful for both Santarella and Hoepli, the latter using it to expand its catalogue with editorial products of a purely technical nature comparable to those published outside of Italy by more famous American publishers (Hool 1918; Warren 1906). Critics of the time recognised this success as demonstrated by the numerous positive reviews that appeared in the architectural and engineering journals of the day.

3 BOOKS AS CATALOGUES OF GOOD PRACTICES

In the early 1920s, Santarella began collaborating with authoritative Italian engineering journals such as *Il Monitore Tecnico, L’Industria* and *Il Cemento Armato,* both with his articles and in his capacity as member of scientific and editorial committees. Using a narrative structure in which science and experience offered a balanced picture of the discipline, in both his books and articles, Santarella highlighted that much-discussed combination of theory and practice. The same formula, already widely tested for his books, was used for his numerous essays and articles, which appeared in the technical journals of the time: sketches, construction details and pictures accompanied calculus formulas, tables and diagrams. While teaching, Santarella was also able to conduct intense professional activities as consultant to construction companies specialising in the execution of reinforced concrete structures: the projects by Santarella – bridges, grandstands, stadium canopies and various roofing systems with innovative prefabricated trusses – represent that pragmatic experimental field of application of the principles of structural dimensioning as well as the technical and construction techniques displayed in his books. Santarella demonstrates his constant ability to deal with professional and building site practices, revealing an approach to the theorisation of structural design still permeated by a purely nineteenth-century empiricism: “As has always been the case with technique, particularly in this field, in which experimental theoretical study is highly complex and indeterminate, the implementation of building practice precedes theory; but the development of the latter will definitely allow progress in applications, minimising the problem of empiricism as far as possible” (Santarella 1930a, IV).

Figure 1. On-site prefabrication of the reinforced concrete truss girders within reusable wooden formwork (Santarella 1931: 346).

However, it is this degree of empiricism derived from building site practice that led to the introduction in Italy of construction techniques that were decidedly innovative at the time. One such case was the design of long span roofs made of prefabricated reinforced concrete trusses: from 1918, Santarella claimed that he had designed and built triple saw-tooth prefabricated trusses made of reinforced concrete, with 20 metre spans, as the supporting structure for the roofing of huge industrial buildings. This means he was ahead of both the design of the large airship hangar roofs made of prefabricated reinforced concrete components promoted by the French engineer Henri Lossier from 1921 onwards on the pages of *Le génie civil* (Dantin 1921), and Nervi’s experiments, which were not patented until 1939 – after Santarella’s death – which led to the construction of his famous hangars for the Italian airforce (Gargiani & Bologna 2016).

Consequently, the roof of the Fossati garage in Biella in 1920 can be considered as one Santarella’s most innovative projects characterised by the highest degree of technical experimentalism (Figures 1–2).

As a result, its designer presented it in several publications of the time. Santarella described the roof as an “efficient, strong, light and, above all, economical construction” (Santarella 1922): the need to make the most of the space available, reducing the number and thickness of the supporting columns to the minimum, was met by using a triple saw-tooth truss system, thanks to which it was possible to create a large space of 20 × 40 metres, without any intermediate columns, measuring a total of 800 square metres (Figure 3). Each roof truss girder was prefabricated on the ground within the building site area, with a series of quick operations, and then lifted and assembled (Santarella 1930c). This prefabricated system and building site organisation were never patented by Santarella but were taken up again later by architects, engineers and companies for the design and construction of long span roofs in post-war Italy and indeed led to the construction of much more celebrated buildings and infrastructures (Iori 2001, 150).

Figure 2. Assembly operation of the reinforced concrete truss girders, previously prefabricated on the ground (Santarella 1931: 346).

The same lightness of structure and speed of execution can also be found in the design and construction of cast-in-place reinforced concrete railway bridges and viaducts, built using innovative and complex formwork systems. For example, analysis of the designs for the bridge over the River Erno, between Solco and Lesa – near Novara – built by the Attilio Sommaruga company in 1926 (Figure 4), and the bridge over the River Brembo – near Brembate – for the Milan-Bergamo motorway, built by the Bianchi-Steiner company in 1927 (Figures 5–6), both with a single span, highlights the result of a construction process that aimed to adopt solutions that were “as bold as they were economically viable” (Santarella 1930c): a balance between structural form and the physical and chemical properties of the concrete used. Santarella himself claimed that the study of these bridges could “enlighten the builder and strengthen the creative intuition of new forms, making them increasingly responsive to the needs of technology” (Santarella 1930c). It is no coincidence that what little literature exists on the subject has already defined them as “two remarkably bold works that honour the Italian technique” (De Ceglia 2007).

A striking example of his design approach with the use of cast-in-place reinforced concrete, which can still

Figure 3. 1920, L. Santarella, Garage Fossati, Biella. Interior view of the roofing system (A. Bologna, private archive).

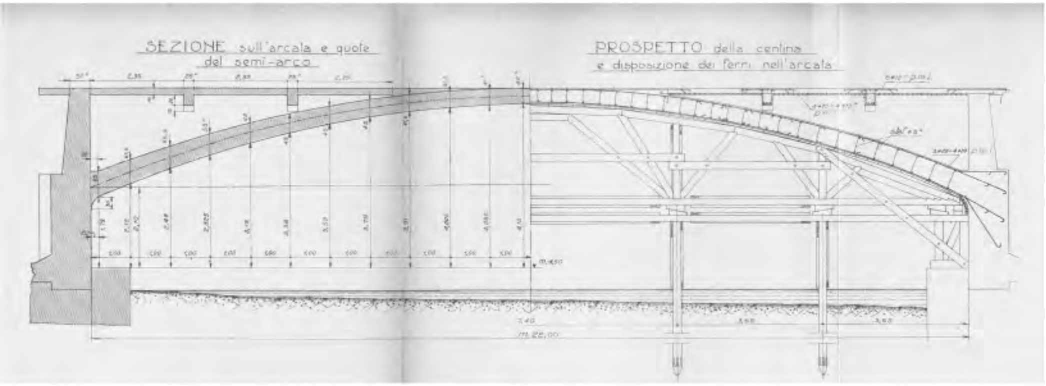

Figure 4. 1926, L. Santarella, bridge over the River Erno. “Section on the arcade” and “view of the rib” (Santarella 1932: tav. 51).

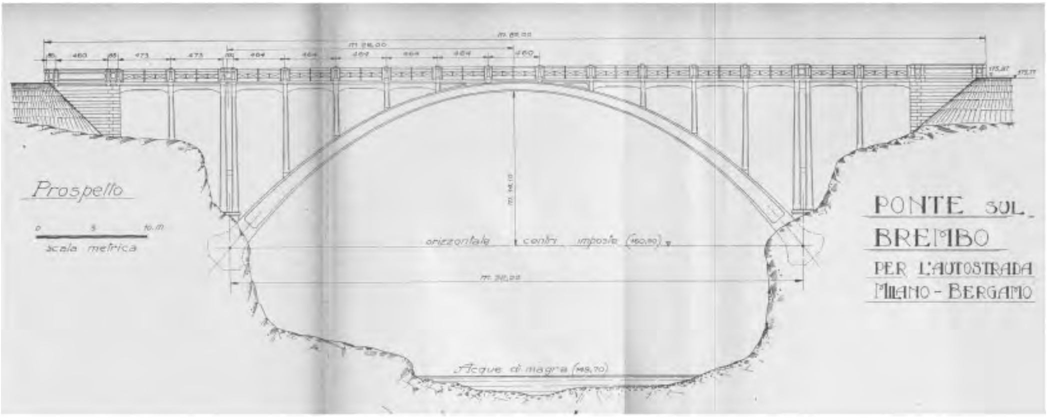

Figure 5. 1927, L. Santarella, bridge over the River Brembo (Santarella 1932: tav. 35).

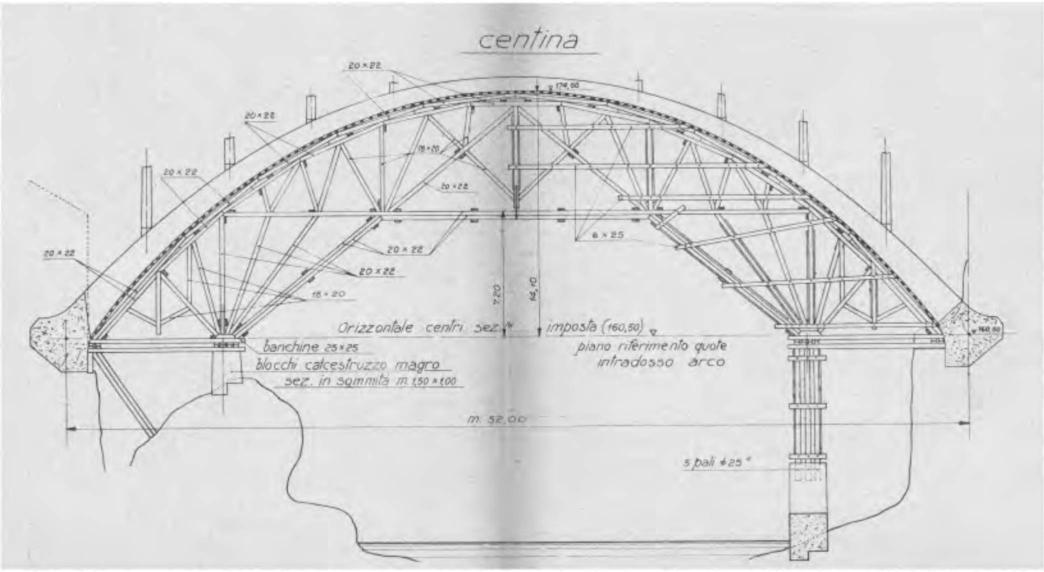

Figure 6. 1927, L. Santarella, bridge over the River Brembo. “Rib” (Santarella 1932: tav. 36).

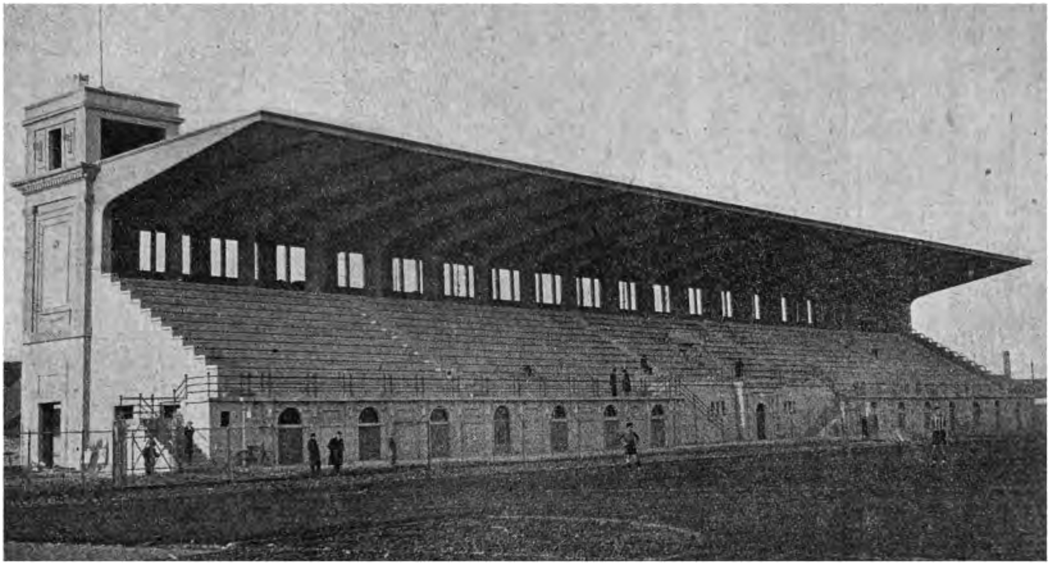

Figure 7. 1928, L. Santarella, grandstand of the Bergamo Stadium (Santarella 1931: 231).

be seen today, is the canopy of the grandstand of Bergamo Stadium (Figure 7), completed in 1928 by the Oscar Gmür company: a structure that can be rightfully considered as the forerunner of the more famous canopy of the covered grandstand of the Berta Stadium in Florence, designed and built by Nervi in 1930. The roof designed by Santarella is made up of a series of cantilevered beams, spaced 4 metres apart, with an overhang of almost 13 metres, joined together by a brick flooring system. This project was also widely referenced by Santarella both in his books and journals articles, presented as good practice in the construction of cantilevered canopies. Nevertheless, the purely technical character of its descriptions, combined with a formal language derived from constructive rationality and mere calculation requirements, were unable to arouse the interest of the architectural literature prevailing as was the case with the more elegant and slenderer canopy of the Berta Stadium or, later, that of the Zarzuela racecourse in Madrid. The structure designed by Santarella lacks the design intention of being a sculptural object, regardless of its structural or construction efficiency. Santarella still saw structures as mere tools to provide a technical response to a static need and not as an expressive factor with the capacity to transform a structure into a work of architecture capable of generating spatial quality. His writings offer a striking example of this limit, which the Italian polytechnic culture of the time – in which he found himself completely immersed – had not yet overcome. His relationships, which we are able to reconstruct today, indicated his close collaboration with the world of the Italian cement-making industry – which was booming at the time – in the exploration of increasingly high-performance concretes, with the world of building components, such as state-of-the-art formworks, or for the use of machinery such as mixers or mechanical vibrators capable of simplifying the casting of concrete mixtures (Santarella 1931, 1932).

These are the specialities that made Santarella one of the most competent and capable professionals in collaborations, as a consultant, with construction companies specialising in the construction of reinforced concrete structures, which were indeed quite bold for the time. Throughout his professional career, he seems to have lacked the relationship with architects that would have been essential to his progressive maturation of that aesthetic and spatial sensitivity in the usage of the structure which, combined with his undeniable ability and technical knowledge, could have led him to conceive works capable of tracing a true poetic in the use of reinforced concrete. Clearly, his premature death prevented this change from happening.

4 CONCLUSIONS

The fifth edition of *Reinforced Concrete* [*Il Cemento Armato*], the last updated by Santarella, was published in September 1935, shortly before his death. From 1953 to 1997, Franco Mattiazzo, an engineer from Milan and Santarella's son-in-law, was commissioned by Hoepli to carry out a progressive and careful review of the texts, drawings and calculation formulas, updating his father-in-law's volumes from time to time and also taking into consideration the evolution in Italian regulations and building technology. Over the decades, the Hoepli manuals published under the name of Santarella – despite the fact that their contents are updated in line with scientific developments in construction technology and the design of reinforced concrete structures – have been commonly used in Italy as textbooks or in support of professional practice.

His early death prevented the path traced by his built structures from generating further and future prolific professional collaborations capable of evolving his compositional and expressive vocabulary from an architectural point of view. The same cannot be said for example for Nervi, who was just five years younger than Santarella and whose youthful production is entirely comparable to that of his colleague.

Several periodicals of the time reported the news of Santarella's death, summarising the unquestionable professionalism of the forty-nine-year-old Italian engineer. The various obituaries highlighted not only the multiplicity of works published but also the figure of a "dynamic and proactive" (*L'industria italiana del cemento* 1935) man, who contributed determinedly to the renewal of the dissemination of the engineering culture of the twentieth century. A few months after his death, in December 1935, the "National Fascist Federation of Cement, Lime, Gypsum and Cement Manufacturers" went to far as to launch a competition to honour the memory of the Italian engineer, with the aim of promoting the development of innovative projects and studies that had a direct impact on the practical and operational field in response to the autarkic requirements of the time (*L'industria italiana del cemento* 1935).

Santarella can, therefore, rightly be considered one of the main forerunners of twentieth century century Italian structural engineering (Iori 2007) characterised both by progressive scientific advancement in the theoretical sphere which analyses and regulates the static behaviour of structures and by a still sometimes purely empirical experimentalism derived from building site practice. In this context, Santarella's name is linked exclusively to the evolution of techniques relating to the use of reinforced concrete, and his personal system of dissemination can be rightfully considered his most significant legacy: the pedagogical approaches pursued, for example, in Mario Salvadori's texts (Salvadori 1980) or, more recently, in those of Aurelio Muttoni (Muttoni 2011), can undoubtedly be considered a logical evolution of Santarella's analytical and publicist criteria.

In conclusion, we can say that, in just twenty-five years of activity, Santarella succeeded, thanks to its publications, in becoming the undisputed authority of his time on the theorising, designing and building of reinforced concrete structures and also a mentor for successive generations of scholars and designers.

The authors consider their individual contributions to the writing of this paper as 50%, resulting from constant debate and joint effort. All the archive research was conducted by Cinzia Gavello. For the sole purpose of academic evaluations, it should be noted that Sections 1 and 2 were written by Cinzia Gavello and reviewed by Alberto Bologna; Sections 3 and 4 were written by Alberto Bologna and reviewed by Cinzia Gavello.

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History of Construction Cultures – Mascarenhas-Mateus & Paula Pires (eds)

Entanglements within an emerging technology: Swiss Federal Railways and early glulam

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ABSTRACT: Many factors contributed to the early success of glue-laminated timber (glulam) in Switzerland following its introduction in 1908. A strongly interconnected network of established players was decisive for the early acceptance and development of such a recent building material. Within this network, the Swiss Federal Railways (SBB) played a decisive role through their early and broad involvement. In the formation of a new practice, they simultaneously represented a wide range of institutions. This paper discusses the role of the SBB in the development of early glulam in Switzerland between 1910–1945.The agency of the SBB will be analyzed here across two levels: the material practice of glulam, i.e., the construction of the material on the one hand, and the social construct of it, i.e., the construction of the material culture on the other. Based on archival material documenting the design process and construction phases of SBB buildings, this demonstrates how a productive network was formed through the agency of SBB and which relationships were crucial to its existence.

1 INTRODUCTION

1.1 *The early glulam network in Switzerland*

The industrial practice of glulam construction in Switzerland began in 1908 when the Swiss engineers Bernhard Terner and Charles Chopard bought the German patent granted to Otto Hetzer in 1906. They developed many extraordinary and internationally acknowledged glulam structures and established an early high-profile timber engineering focus in this country. The development of early glulam practices is particular in Switzerland for several reasons.

The existing extensive timber construction knowledge and innovative spirit of the craftsmen often gets referred to here. However, even more than the construction practitioners and the patent owners, the early and broad involvement of a wide range of institutions was decisive for establishing such a young building material within a strongly interconnected network of established players: renowned architects who integrated glulam almost without hesitation, partly even in a representative role; licensed contractors-carpenters who embedded the new technology in their traditional practices and, consequently, proposed design changes; clients who pushed for the highly competitive price and early modern image; and public authorities and professional institutions that quickly established it as an official construction alternative and contributed to the standardization and codification of the practice on a national scale.

Among these actors with different interests, competences and influences, one institution played a key role and even simultaneously took on many of the aforementioned roles. The Swiss Federal Railways (SBB) was not only one of the early and major clients of glulam but it also held a pioneering role in legitimizing glulam and attributing it with high technical recognition as an equally acceptable construction material similar to other modern building materials of the time, such as steel and concrete.

1.2 *The early stages of the SBB*

The first systematic approach to the provision of railway communication in Switzerland took place in 1850 with planning for a railway which connected the main cities of the country. In 1872, the federal government took over the right to grant concessions for new constructions from the cantons. It thus became necessary to submit all railway plans to Bern for approval with federal engineers appointed to supervise construction work and check all safety measures and appliances. This was an important step for the young institution in order to centralize all the decisions for future plans. Thirty years later, in 1902, the *Schweizerische Bundesbahnen* (SBB), (Swiss Federal Railways) was founded. Until the early 1930s, the country was a nationwide railway infrastructure construction site (Allen 1958).

In the initial phases, most of the structures were built mainly in timber, at low cost. Later on, steel replaced timber for the more representative halls, and by the turn of the 20th century most of the wooden bridges had been replaced by steel for fire prevention (Seraphin 2006). Very soon the high cost of steel maintenance,

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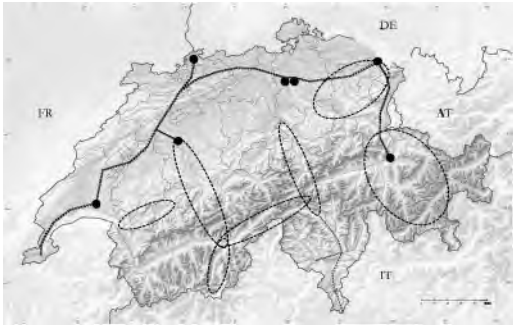


Figure 1. The black line stretching from west to the east shows the first railway projected in Switzerland on a national scale in 1850, connecting the main cities, but also the first licensed contractors of glulam (black dots). Dotted lines indicate the construction sites of the regional railways by the 1930s.

damaged by the smoke of the engines, became a major problem and resulted in the revival of timber in the railway infrastructures.

The railways demanded projects ranging from platform roofs to power plants, locomotive depots, repair workshops, but also bridges and scaffoldings for stone and concrete viaducts. This broad spectrum of projects together with the public investment and responsibility for the safety of the public rendered the SBB a hugely influential and decisive actor in early glulam (Figure 1).

1.3 *Why the SBB?*

By picking up one single actor, a certain class of phenomena, objects and events are in fact privileged over the remainder and the dynamics of the network are described within the entanglement of one specific actor. In this context, it appears necessary to clarify what makes the role of the SBB particular, and what kind of knowledge and insight can be gained through this study which cannot be attained by putting the focus on other actors. Two key points should be noted in order to respond to this question:

First, it should be highlighted that the SBB, then a young federal institution, established itself in parallel with the young building material, glulam. This close trajectory of growth and transformation caused a mutual influence between them and, therefore, the agency of one on another.

Furthermore, it should be noted that the SBB was one of the few actors whose role can be followed both in the material practice of glulam on the one hand, and in the social construct of it on the other; or, in other words, construction of the material and construction of the material culture. This simultaneous evolution of the product and the process through the agency of the SBB is the second argument why the study is particularly relevant.

Based on archival material documenting the design process and construction phases as well as reports and letters from the clients, designers and contractors involved, this will show how a productive network was formed through the agency of SBB in the first four decades of glulam in Switzerland.

2 THE SBB AND GLULAM

2.1 *Introduction of glulam to the SBB*

The mass production of iron in the second half of the 19th century led to an inevitable setback for wood as a structural material. Many of the existing iron roofs of railway stations or depots, however, displayed considerable damage due to corrosion. Glulam was considered particularly suitable for the SBB infrastructure as it was seen more resistant to the acid smoke of steam engines. An important milestone was reached in 1911 when the SBB built a locomotive depot in Bern that very soon gained international recognition. The SBB then advised all of its subdivisions to use timber instead of steel for halls and sheds. This preference for a new material could be justified when it led to structurally more performative, economically more beneficial and esthetically more appealing projects. Moreover, the SBB was a client that had previously made pioneering projects in other structural materials such as regular timber, steel and concrete, and had thus accumulated comprehensive knowledge of structures and materials (Rinke 2018). This extensive knowledge increased the agency of the SBB when dealing with the young construction material glulam.

2.2 *Agencies of the SBB*

Beyond its role as a client, particular in terms of the volume, variety and infrastructural nature of its projects, SBB entangled with the other actors and developed the glulam practice mainly through three agencies: load testing, material research and designing. A deeper look into the nature of these agencies will now be undertaken to understand the role of the SBB in constructing both glulam and a material culture.

3 AGENCIES: LOAD TESTING

3.1 *Introduction to testing*

Dealing with the mass transportation of thousands of people every day, the SBB aimed for high degrees of safety when projecting its infrastructure. Accordingly, they demanded extensive loading tests in order to ascertain the required performance of the structure, and to verify the assumptions made in analytical models and calculations related to actual behavior.

The testing regime, comprising all required methods and instruments, was defined by the SBB collaboratively with the Eidgenössische Materialprüfungs- und Forschungsanstalt (EMPA, Swiss Federal Laboratories for Materials Science and Technology). Founded in 1880 as a subdivision of the Polytechnic Institute of Zurich, the EMPA was a technical laboratory for

Figure 2. Footbridge built on the occasion of the National Agricultural Exhibition of 1910 in Lausanne, with a span of 27 m. The loading test was initiated and carried out by the SBB.

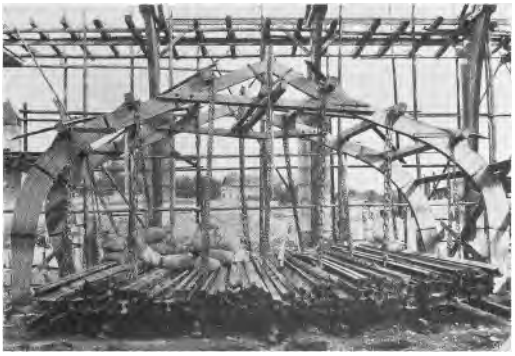


Figure 3. Loading test of the first glulam project commissioned by the SBB for a locomotive depot in Bern, 1912.

all kinds of material tests which was co-funded by the industry and the federal state. However, the SBB, with its highly specific projects and loading conditions, also developed its own testing regime in parallel to the EMPA.

As soon as the EMPA was established at the Polytechnic Institute of Zurich (ETH Zürich) in 1880, systematic research started on wood as a structural material. This institute, as part of ETH Zürich, was a regular way through which academia could exert agency in research on construction materials and publish the results in technical journals.

As regards glulam, the SBB conducted systematic loading tests on these structures years before they were subject to testing and research by any other institution (EMPA or academia). This exclusive fundamental knowledge bestowed authority on the SBB: while no timber code or official regulation on timber construction existed, the SBB could legitimize the use of glulam in construction. In the absence of a timber building code, the SBB thus set a quasi-standard for glulam structures, defined a testing regime and established criteria for the performance of glulam structures. This particular influence of the SBB effectively contributed to the early acceptance of glulam.

The first loading test of glulam carried out by the SBB dates back to 1910. A pedestrian walkway in Lausanne served to connect the two parts of the Confederation Agricultural Exhibition in 1910, which were separated by a street. This footbridge is commonly referred to as the first glulam structure in Switzerland (Figure 2).

Since the footbridge crossed a tram line, the railway department found the occasion for a loading test in order to assure the safety of its passengers and its infrastructure. This test, as reflected in the reports by the SBB control engineer, "had a very satisfactory result" (Haddadi 2020). Although in similar situations loading tests were demanded to be planned and carried out by the project designer (architect or engineer), the SBB itself took over all aspects of testing.

Two years later, when the locomotive depot in Bern had to be approved, the SBB ran the loading tests which enabled its first glulam building. The depot very soon gained an international reputation and became an exemplary model for modern timber structures in the professional circles of railways-related constructions. In view of the novelty of the construction technique, the railway building department emphasized the expediency of carrying out loading tests until structural failure. It was intended to show to what extent the static calculations provided by the engineers Terner & Chopard conformed to the actual behavior of the structure. Terner & Chopard were required to provide scaled samples of their structure, frame girder, (1:3) and to carry out the testing while the SBB covered all related costs. The girder was loaded with hanging railroad tracks at specific points.

The girders were tested from May 29 to June 3, 1912 in the presence of representatives of the SBB, the engineers Terner & Chopard and their contractor, Fietz & Leuthold, licensed for the execution of glulam structures in Switzerland (Die Hetzersche… 1911).

The testing procedure was planned by the SBB control engineer. The purpose of these tests was not only to prove the capacity of the structure under certain loading conditions but also to obtain a deeper understanding of the material behavior and the influence of glulam fabrication on its performance. For instance, during the first phase of the test, the breaking resulted in joints opening in the glued lamellas, which prompted the SBB to demand further tests to determine the shear strength of the material, and to determine the influence of the fabrication process on the strength of the material (Figure 3).

For these tests, the SBB established a direct connection with the contractor; the SBB again designed the test setup, process and machinery, and the contractor took care of the fabrication of the test samples. The loading test was performed in the contractor's workshop. This cooperation between the SBB and the contractor was beneficial to both parties. The contractor was informed about the expectations of the SBB over the usage of the new material and their criteria for evaluating it. The SBB, in turn, and through different projects, obtained insight into the different tools and techniques used by different licensed contractors, and learned about the most recent developments in the fabrication process from across the country. Here, it should be noted that the construction of the material (the glulam pieces and even the glue itself) was planned and carried out with slight differences by the licensed contractors. This comprehensive overview of different construction methods enabled the SBB to find common solutions for unsolved problems related to the fabrication which directly influenced the construction of the material itself.

3.2 *The cinema Scala project*

Constructed in 1916 in the Swiss city of La Chaux-de-Fonds, the cinema Scala was the collaborative project of René Chapallaz and Charles Edouard Jeanneret (Le Corbusier). When the decision for the construction of the city's first cinema was announced, a competition for ideas was set up. No first prize was awarded. Le Corbusier succeeded in convincing the client to entrust him with the execution of his project (La Chaux-de-Fonds…1987). The structure of the main hall was designed in reinforced concrete on which a glulam structure for the large roof rested.

The architects pushed the city authorities, mainly driven by Le Corbusier, to authorise the execution of the glulam roof despite their repeated refusal. Before granting permission, the authorities required a loading test of 500 kg per m^2 in the presence of a delegate from the city's building department. Assuring the stability of the glulam structure, Le Corbusier referred to reinforced concrete: "the structure has been calculated by the engineer's specialist in reinforced concrete, based on the rules dictated by the federal law, which are very strict and imply absolute security". By referring to concrete, a material that had already at that time established practical regulation, Le Corbusier saw glulam technically as an equivalent. The cantonal authorities backed the approach of the city to require a loading test, emphasizing that "it is not enough that the structure is calculated by specialized engineers, but it is the execution of the work which plays an important role". They also stressed that the duty of the authorities was not to verify the calculations but to control the executed work. Le Corbusier, at least at the first stage, refused to pay for the test since he believed that "he had taken all the precautions in order to insure the absolute stability of the structure" (Le Corbusier 1916).

In this conflict, the SBB could eventually solve the technical and legal controversy by exercising its particular and already established authority in the field of glulam construction. The authorities organized a jury of experts to oversee the required testing and to decide on the performance and safety of the structure. This jury was headed by the SBB. The test was launched in November 1916, attended by the cinema's owner, the architects, the city and cantonal authorities and Fritz Hübner, the SBB control engineer. The final technical recommendation was left to the SBB and Hübner specified in his report that the girders were stable and would not need any modifications (Hübner 1916).

Gaining insights into almost all facets of glulam through their involvement in various different infrastructure projects incorporating the material, the SBB gained unique technical knowledge. Based on this knowledge, it mobilized a series of resources to provide solutions for problems which occurred in the early phase of the adoption of a new material in the construction practice. The agency of the SBB, beyond its legitimizing role, extended to the design phase. For instance, the SBB strongly advised in its report to protect the footings of the glulam girders in the west façade against rotting, and refers to this as a very difficult issue which deserves to be studied in detail.

3.3 *Conclusion on the role of the SBB*

The different glulam projects discussed in this study demonstrate the particularities of the early loading tests: firstly, those tests were mainly initiated by the SBB, and within their role as a client. However, the example of cinema Scala showed that not all glulam structure clients held the same interest in the new material; neither initiating the load testing, nor welcoming the demand for testing by the public authorities. The fact that beside private clients, such an important public institution with a high level of demand for safety became involved in the early glulam network, demonstrates their particular role in pushing the development of the material. The third particularity of the early loading tests is the organization of the testing process in such a way that a plurality of actors might be considered in the early testing regime. In contrast to the testing processes performed at professional testing laboratories, this early and sometimes improvised testing network brought all the actors to the direct observation and monitoring of the testing process. From the selection of the wood, production of the glue, process of gluing and laminating, to the design decisions, but also criteria for consideration to examine the structure's performance. The simultaneous performance of the agency of the actors accelerated the process of finding solutions in the case of ambiguities and problems in the testing process but also, and more importantly, generated a global awareness of the interests, the competences, and the influences of other actors towards the new material. Le Corbusier, for example, perceived glulam as a much cheaper material to replace concrete, thus he was not interested in carrying out tests that added extra costs to the project. For the authorities, glulam was a new material, with an unknown fabrication process and thus unknown structural qualities. For the contractor, glulam was a new gateway for the timber market. It could guarantee the future of sawmill plants and carpentry shops which were suffering from the prejudices of the construction market towards traditional timber structures. Testing glulam and legitimizing its practice would then save their workshops which were in danger of closing due to the prevailing influence of steel. And finally, for the glulam patent holders, this constellation was only beneficial as the early recognition and legitimization of the practice were fundamental steps towards a flourishing market and profitable returns from the investment made in the patent.

In this network, the SBB, as a client, shared the interest of Le Corbusier in glulam and, as an infrastructure provider, shared the responsibility of the authorities regarding public safety.

4 AGENCIES: MATERIAL RESEARCH

Following the establishing of EMPA, general research into wood started in 1880, focusing mainly on the testing methods and properties of structural timber. This research played only a minor role given the relevance of timber at that time, and continued until 1896, when the last series of the results was published. The EMPA then shifted its research focus away from timber for a period of three decades. This situation can be explained by the decline in interest in timber as a structural material due to the mass production of steel. Nonetheless, the first Swiss timber building code was published by EMPA in 1925. The publication of this code can thus not be explained only in the context of the research within this institution. The following section clarifies how the research on timber carried out by the SBB during those three decades resulted in the development and publication of the first timber building code in Switzerland.

In the backstage of official testing and research on steel by the EMPA, the pioneers of glulam in Switzerland were applying and promoting this new material until it became a rival for steel. Different testing, as discussed in the previous section, resulted in systematic research into glulam, and glulam pushed the general research on timber. The results of this research were published in technical journals at that time by the glulam patent holders and mostly in collaboration with the SBB. They laid the groundwork for the development and publishing of the first timber code in 1925. Publishing the results of this research representing the latest knowledge on the field meant the SBB becoming the leading scientific authority on glulam practice.

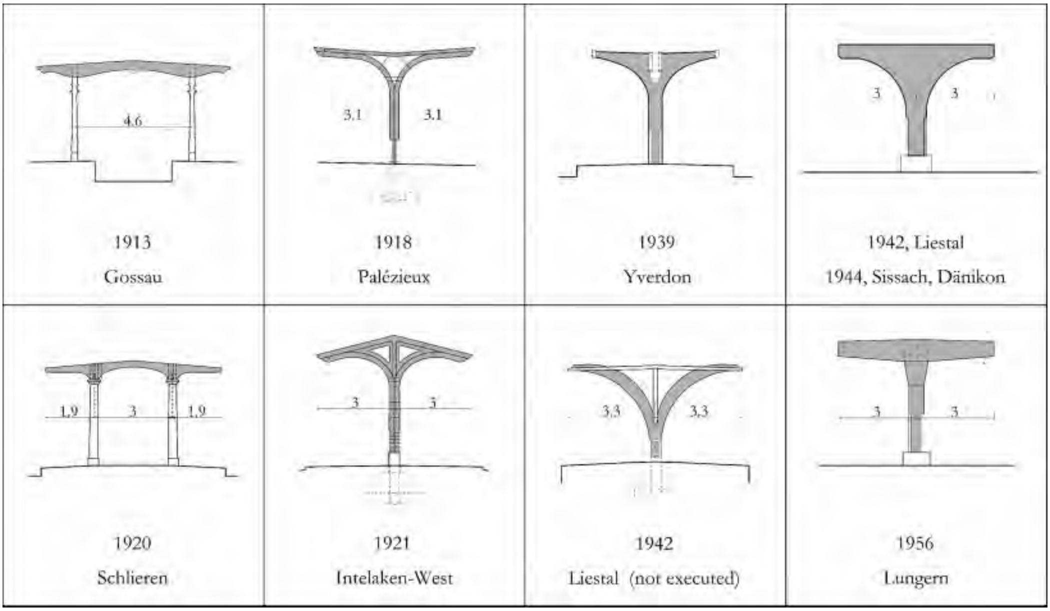
The first timber code reflected the need of the construction market to recognize timber and regulate its usage as a structural material when modern timber structures such as glulam were gradually replacing steel. This revival period of timber was followed, at the end of the decade, by the decline in the global economy and the Great Depression that strongly influenced the heavy industries and the construction sector. This situation continued throughout the 1930s until after the Second World War, when all major industries, including the construction sector, suffered from the shortage of steel and cement. In this context, timber was continuously promoted within the construction sector. Two main reasons for this can be highlighted: Firstly, Switzerland had access to local timber resources, and secondly, the process of timber as a raw material in order to adapt it to the needs of the construction market needed far less energy than other materials, such as steel and concrete. It is within this context that timber was recognized and labeled as a “national material” in the 1930s, and powerful lobbies promoted recourse to timber in the construction sector, among others. Although this period saw significantly fewer construction sites, the importance of timber intensified and so did the research on it and, particularly in Switzerland, on glulam.

One part of this research focused on the glue used in the glulam production process. This research was mainly led by the EMPA. Another aspect of the research was on the fabrication of glulam elements, and the construction of glulam as a material. This aspect was mainly studied by the SBB. The findings and experiences gained during the execution of different projects provided the SBB with a global and holistic vision on different approaches to constructing this material and drawing up regulations in order to standardize this practice throughout the country while also setting criteria and semi-standards for the SBB subdivisions to apply for quality control over glulam manufacturing. A two-page document entitled “Regulations for Glue-Laminated Timber Structures”, published in 1943, covered different issues from the selection of woods and type of the glue to the conditions for gluing and laminating in the carpentry workshops (Bestimmungen…1943). This served as the guideline for all subsequent construction projects and became valid for the entire SBB area following the 7 January 1944 decree issued by the General Management Department for Railway Construction and Power Plants. The following year, in 1945, the first EMPA “Guidelines for Glue-Laminated Timber Structures” were published (Richtlinien…1945). This report in fact reflected the internal SBB regulations, which had already been published internally.

In conclusion, the material research carried out by the SBB and published in the technical journals at that time obtained a dual function: on the one hand, systematic research on glulam pushed the general research on timber and laid the groundwork for the development and the publishing of the first timber building code in 1925, at a time when EMPA had shifted its research focus away from timber. On the other hand, publishing the research results meant demonstrating the latest knowledge on the field and becoming the leading scientific authority on glulam practices. The usage of glulam by the SBB, together with such authorities, legitimized its practice at a time when there was no official timber code.

5 AGENCIES: DESIGNING

In addition to its application for the roofing of depots and halls and for the scaffolding of bridges and viaducts, glulam was also widely used by the Swiss railways for their platform roofs. These structures are, within the focus of this study, also of interest: open



1913
Gossau

1918
Palézieux

1939
Yverdon

1942, Liestal
1944, Sissach, Dänikon

1920
Schlieren

1921
Intelaken-West

1942
Liestal (not executed)

1956
Lungern

Figure 4. Development of the SBB's platform roofs' design. Projects of the last column at right are designed by the SBB, and the others by the engineers Terner and Chopard in collaboration with their licensed contractors.

to the public, they serve as a representative image of the SBB as a federal institution. In this context, the SBB should be considered, beyond all its other functions in transport and in promoting new materials and new techniques, as a complex of permanent exhibitions for national and international visitors and users of its infrastructures. The design of this category of structures, representing a federal institution, demanded, consequently, also formal and aesthetical considerations. A deeper look into the design development of platform roofs in this section will serve to understand the role of the SBB in designing glulam structures.

After the patent protection of glulam in Switzerland expired in 1924, the concept became available to any institution or individual for their free usage. The SBB, who had gathered broad construction knowledge of the material over the years, made significant steps in the design of glulam structures.

Figure 4 displays different glulam designs for platform roof structures. At the very beginning, glulam replaced other materials: in the roofs, glulam elements mainly replaced ordinary timber or steel girders, without any particular curvatures and paired with an accompanying material for the supporting parts which were constructed principally in timber or concrete (Figure 4: projects for Gossau and Schlieren). Later on, the design principles changed in favor of facilitating the human traffic on the platforms resulting in the reduction of supports to one central column. The sheds were then two curved glulam cantilevers, connecting to the central column which rested on a concrete base, anchored by means of iron shoes (Figure 4: projects for Palezieux and Interlaken-West).

This shift in the design opened new questions regarding the effect of quite sharp curves running from the column to the cantilevered arm. In all the designs to be described, the most important supporting sections consist of, without exception, glulam pillars with full rectangular cross-sections. The inclination of the roof's sloping parts for drainage purposes, which also affected the formal conception of the structure, strongly influenced the curves of the cantilevered arms.

The experience gained through these projects influenced the design of not only the succeeding platform roofs but also other SBB structures: sharply bent lamellas and strong curves which were unprecedented in former projects of any kind, entailed testing and research on the elastic and plastic behavior of the lamellas under sharp bends. These tests were mostly carried out on the portions of structures with basic geometrical forms, straight beams, parabola or circular curves in order to comparatively study the influence of form on the performance of the girders.

This research resulted in more compact and basic geometrical forms for the platform roofs (Figure 4: projects for Liestal, Sissach, Däniken). The projects for all three roofs with basic compact geometrical forms were established and developed by the SBB Construction Department (Wichser 1943). This tendency for structural elements with basic forms was not restricted to the platform roofs and can be seen in the workshops and depot buildings of the SBB with glulam straight girders for roofing. The simultaneous emergence of glulam columns in combination with the straight glulam girders for roofing indicates a particular phase in the development of the material: glulam is no more only a replacement material for some roofing structural components, it has become a material with known properties that can be used in practically every structural part of the buildings.

6 CONCLUDING REMARKS

The development of early glulam practice is particular in Switzerland for several reasons. One of the principal reasons is the early and broad involvement of a wide range of established players (institutions or individual practitioners) in the early glulam practice network. However, among these actors, the SBB played a key role. The SBB contribution, as demonstrated in this study, reached beyond its initial role as a major client of glulam for its various projects with this contribution understandable through its role in establishing an early network, within which a complex entanglement of roles and institutions resulted in an early acceptance of the material and regulation of its practice.

In this network, entrepreneurs, industrial, commercial or scientific organizations and institutions, authorities, clients, designers, professional practitioners, and material suppliers with different interests, resources, competences, projected, performed, contested or, in other words, were entangled when establishing and further shaping glulam practices.

As illustrated by the examples described in this study, the direct association of the actors together and with the SBB became possible through this network. These associations revealed the fields where their interests converged or were in conflict. In addition, this study clarified that the SBB shared common interests in the new material with some actors, but also common concerns about its performance with some other actors. These areas of common interest and concern (examples include the pedestrian bridge project in Lausanne, the locomotive depot in Bern, the cinema Scale in La Chau-de-Fonds, and many others) shaped the very particular agency of the SBB in this network. Given the infrastructural character of their structures affecting the safety of the public, the SBB demanded levels of strength and performance at a time when no timber code yet existed. Regularly applying the material in its projects, the SBB gave glulam a technical recognition as an equally acceptable construction material and, through systematic loading tests and material research, the SBB laid the groundwork for the development and the publishing of the first timber code in 1925 (one of the first industrial timber building codes in Europe), and later the first regulations on glue-laminated timber structures in 1945.

In the context of this study, the construction of the material was understood beyond the technically driven arrangement of the material's components. The particular role of the SBB in the network of early glulam illustrates the mutual and simultaneous development of the construction of both the material and the material culture. This furthermore demonstrated that the material's construction was in fact strongly and reciprocally related to its social construct, and the SBB was the particular actor that pushed the very early development of these two interdependent fields.

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History of Construction Cultures – Mascarenhas-Mateus & Paula Pires (eds)

Technique and architecture in the work of Manuel Sanchez Arcas, 1920–1936

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ABSTRACT: Manuel Sánchez Arcas had a successful career as an architect. Based in Madrid until the Spanish Civil War broke out, he was part of the team of architects in charge of developing the Ciudad Universitaria campus. In collaboration with Eduardo Torroja, he designed and built Hospital Clínico San Carlos, Central Térmica, and Pabellón de Gobierno. A leading figure of Instituto Técnico de la Construcción y la Edificación and Centro de Exposición e Información Permanente de la Construcción CEIPC, he also carried out relevant theoretical work promoting and disseminating modern construction and architecture through workshops and writings. This paper focuses on the buildings and writings of Sánchez Arcas. It discusses his efforts to integrate modern building services and techniques in the architecture of his time, a little-discussed aspect from the standpoint of the history of construction.

Manuel Sánchez Arcas (1897–1970) received his architecture degree in 1920 in Madrid where he worked until the Spanish Civil War in 1936. Sánchez Arcas, who was very active politically, was disqualified in perpetuity from practising his profession by Franco's regime, and lived in exile in the USSR, Poland and the German Democratic Republic.

1 MANUEL SANCHEZ ARCAS AND EDUARDO TORROJA ON THE CIUDAD UNIVERSITARIA PROJECT IN MADRID

Manuel Sánchez Arcas brought a wealth of experience and a well-defined architectural proposal to the "Oficina Técnica" team charged with developing the Ciudad Universitaria complex. He had already shared his ideas in a questionnaire prepared by Fernando García Mercadal (who is considered to have introduced modern architecture to Spain) and published in *La Gaceta Literaria* on 15 April 1928 (García Mercadal 1928, 6).

Sánchez Arcas strove to find a modern architecture that was free from style. His goal was to provide an adequate form for the new, varied programmes of a modern society, while building up a city, all by taking account of industrial needs. He felt that decoration was intended to be more than a mere add-on as in the styles of the past. Rather than rejecting it, decoration had to reflect a building's constructive essence – it had to be the sublimation of a building's unique features.

The son and the brother of doctors, he had a profound understanding of the highly specialized architecture required of a hospital. Sánchez Arcas combined an understanding of architecture as scientific construction with enormous ability and his awareness of European and US architecture.

Eduardo Torroja's expertise, on the other hand, was limited to civil engineering projects, with virtually no experience in the structure of buildings.

Their first project together was a pavilion for the Ciudad Universitaria Construction Board. It was built in the spring of 1931 as a prototype for testing the structure, external and internal joinery, finishes and materials that were to be used in all other campus buildings. Because of the nature of the works and the scarcity of resources, working methods were to take on cardinal importance.

However, it was only at Hospital Clínico de San Carlos (1931–5) that Sánchez Arcas's proposals were to crystallize, corroborated by the efforts of Torroja.

Hospital Clínico de San Carlos, a university-affiliated medical centre, is closely linked to the School of Medicine through its triple function as a teaching, research and care centre, and its building programme is similar to that of the Medical Center in New York (1925–8), which Sánchez Arcas visited during a business trip to the United States and Canada (Figure 1).

Putting into practice his ideas about how new architecture should be, he brilliantly resolved its organizational needs through a solution that turned Hospital Clínico de San Carlos into one of the world's best hospitals in its day (Hernando de la Cuerda 2016, 383).

During construction, the pair fully developed a method of structural systematization, differentiating two types of structure:

On the one hand, the careful layout of the pillar structure on the ground plan functionally enables a planned and flexible relationship between the

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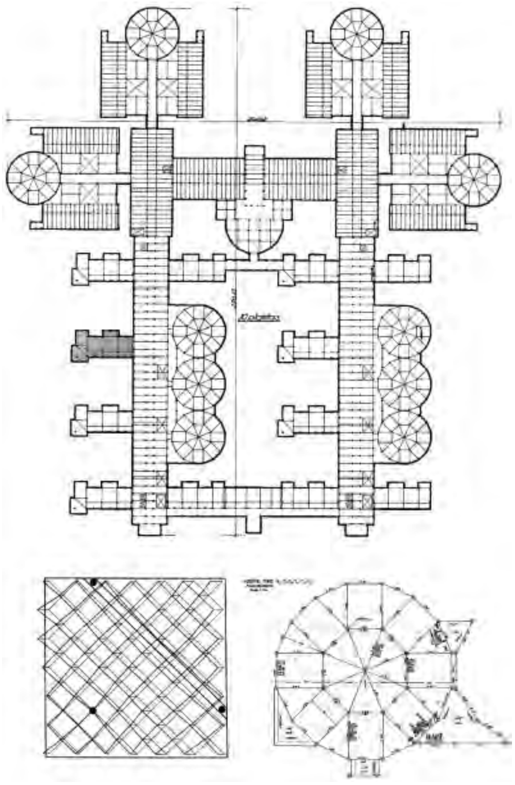

Figure 1. Plan of the “Hospital Clinico”, showing the location of the “especiales” – unique – structures: operating theatres, and terrace-solariums on corners to take advantage of southern sunlight. Bottom left: deflection of reinforced concrete cantilever slabs supported by three pillars in the solariums. Bottom right: skylight in the roof of an operating theatre. (Torroja Miret 1936, 65) Archivo Torroja, CEHOPU-CEDEX, I-ETM-095-03.

circulation of personnel and the different specialities in the hospital. In construction terms, these are what Torroja called “*estructuras corrientes*”, or common structures (Torroja Miret 1936, 48). Formed by repeating elements (beams, slabs and supports), the organization of the work is more important than any technical issues.

On the other hand, the sublimation of unique features, as proposed by Sánchez Arcas, is embodied here in the constructive expression of the solution given to the overflying reinforced concrete of the solariums and the skylights in the operating theatres. Sánchez Arcas had already experimented with these ideas at a hospital in Toledo (1926–30) and finally rolled them out in his entry for the Logroño hospital competition (1929), in which he tried a differentiated formalization of terraces-solariums in patients’ rooms similar to those of Hospital Clínico (Figure 2).

These “*estructuras especiales*”, or special, unique structures (Torroja Miret [1958] 1999, 96–101) represent a technical challenge and call for a specific theoretical study. They may even require producing reduced-scale or life-size models, depending on each case.

Figure 2. The solariums, all located on corners to take advantage of southern sunlight, are differentiated by using a reinforced concrete cantilever square-plan slab supported by three pillars. Archivo Torroja, CEHOPU-CEDEX, I-ETM-095-09/C.

The solariums, all located on corners to take advantage of southern sunlight, are differentiated by pushing out the planes of south-eastern and south-western façades using a reinforced concrete cantilever slab supported by three pillars. Operation was tested with an in situ load test using a life-size slab, similar to what would be done with laminar structures at Hipódromo de la Zarzuela (Figure 3).

Each operating theatre is a circular room with a span of 21.4m and a large polygonal skylight almost 10 m in diameter, for which a smaller-scale model was built at the *Investigaciones de la Construcción* ICON company. Set up by Torroja to develop empirical procedures for the verification of one-off structures, ICON became a powerhouse in both the construction of scale models and measurement techniques. The company was also responsible for the laminar roofing models for Mercado de Algeciras and Frontón Recoletos (Rodríguez García & Hernando de la Cuerda 2009, 1259) (Figures 4, 5).

For on-site installations, Torroja was to develop a method for the graphical representation of drawings, the “*Sistema de notación Torroja*”, or Torroja notation system. Designed for a smaller paper format, it made it easier to handle drawings on site (;ntuña 2003, 125; Torroja Miret 1936, 56). By unifying dimensions and establishing a defined number of standard

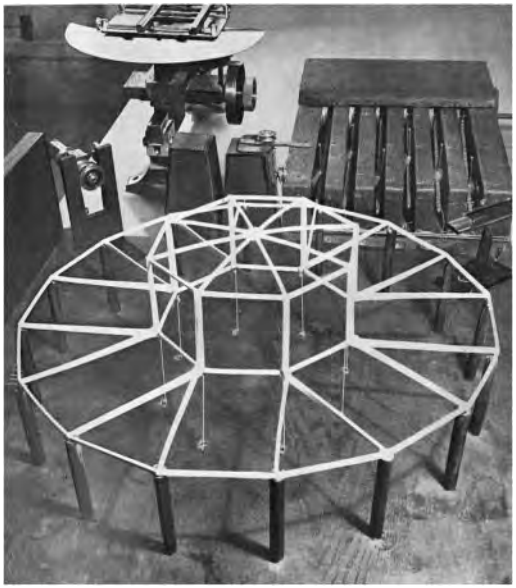

Figure 3. Life-size model built in situ. Load test for operating of the reinforced concrete cantilever slab supported by three pillars, at Hospital Clínico. Archivo Torroja, CEHOPU-CEDEX, I-ETM-095-01.

Figure 4. The polygonal skylight model, built at the "*Investigaciones de la Construcción*" ICON company, for the operating theatres of the Hospital Clínico. Archivo Torroja, CEHOPU-CEDEX, I-ETM-095-08-C.

reinforcements, calculations became more accurate and efficient, and errors were minimized both at the office and on site.

At the same time that Hospital Clinico was being constructed, Sanchez Arcas and Torroja built the Central Térmica heating plant. This building is representative of how Sanchez Arcas approached the logic of a project by giving shape to new programmes, without trying to develop any aesthetic form conceived a priori.

As a starting point, the power station should not depend on a single type of energy. This makes it necessary to use two types of heating system that complement each other in terms of timing. The two Velox boilers, fed by fuel oil, become fully operational in a few minutes, and the Borsig boiler, fed by coal, has greater inertia in its operation. The layout helps to meet fire safety requirements, while determining the shape of the building, with its two perpendicular spaces and the coal hopper at the meeting point.

The two buildings have a reinforced concrete structure made up of pillars, beams and floor slabs.

The spaces are different in size and are fundamentally shaped by the size of the boilers. A steel frame with a bridge crane is added for maintenance and cleaning.

This heat production area conditions the remaining part of the complex, which also includes an office area, workshop, garage, warehouse and a house with a garden for the plant manager (Figures 6–8).

For this innovative centralized heating system, which also included 12 substations and a network of accessible and registrable distribution galleries, Sanchez Arcas and Torroja were advised by Brown Boveri.

Figure 5. Reinforced concrete structure of the polygonal skylight in the roof of an operating theatre. *Ingeniería y Construcción* 127, July 1933. Archivo Torroja, CEHOPU-CEDEX, I-ETM-095-02.

Figure 6. The building of Central Termica Ciudad Universitaria (García Braña; Landrove & Tostöes 2005).

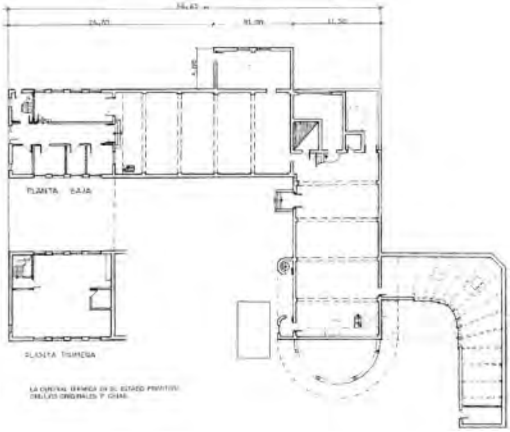

Figure 7. Plan of the Central Termica Ciudad Universitaria Drawing by Pilar Chias Navarro.

SOCIEDAD ESPAÑOLA DE ELECTRICIDAD BROWN BOVERI

AVDA. CONDE PEÑALVER, 21 - MADRID - APARTADO 695

Generador BROWN BOVERI-VELOX para la calefacción a distancia de las distintas dependencias de la Ciudad Universitaria de Madrid para producir 13.300.000 cal. en forma de agua caliente de 190° C.

Figure 8. Advertisement for the Brown Boveri company showing the Velox boiler installed in the Central Termica building. *Hormigon y Acero* 16, 96.

2 THE TECHNICAL INSTITUTE FOR BUILDING AND CONSTRUCTION, 1934–6

The experience gained at the building works for the Ciudad Universitaria established the bases for the *Instituto Técnico de la Construcción y la Edificación*. It was founded in Madrid on 14 November 1934, the result of the enthusiasm of a group of architects and engineers who agreed to set up a private association to encourage progress, improvement and dissemination of Spanish construction techniques, as reflected in the Society's aims, defined in the Articles of Association of its founders (*Hormigon y Acero 6* 1934).

It is significant that, of the members of the executive committee comprising Modesto López Otero and Alfonso Peña Boeuf as president and vice-president respectively, Manuel Sánchez Arcas, José María Aguirre, Gaspar Blein and José Petrirena as board members, and Eduardo Torroja as secretary, a majority were related to the works at the Ciudad Universitaria. As for the spirit of the group, it is worth recalling here the words of two of its founders, an architect and an engineer – López Otero and Aguirre – years later to commemorate its 25th anniversary. Modesto López Otero wrote: "At our Institute, we considered construction techniques from a single concept: we do not draw any distinctions between architectural construction and engineering construction; we do not opt for the false dichotomy of differentiating the useful from the beautiful" (…) "Among other things, because we consider that the creative process in an engineer's work is, to a certain extent, analogous to that of an architect, differentiated only by the degree of rationality, emotional value, logic, sensitivity, all ingredients that can be seen to be present in both processes, although with a different degree of mastery, intensity and consequence" (Lopez Otero 1960, 7).

José María Aguirre explained how they felt it was necessary, at that time, to create a body that could carry out the research the construction industry deserved but could not, for reasons of economy, be undertaken in every construction company as was the case abroad. In other words, the Institute attempted to be, above all, a centre for experimentation, taking advantage of the extraordinary human resources available, to combat the scarcity of the economic resources: "In Spain, there was a very young generation of architects and engineers with major concerns and enormous desire to improve" (…) "These young elements, very well trained and very studious (that is something young people today have to learn, they were very studious), were restless enough to raise the level of construction in Spain to even higher levels than before" (…) "The Institute was born out of conversations among enthusiasts and that was its only birthright, purely with enthusiasm, with no resources (Aguirre Gonzalo 1960, 10) (Figure 9).

One of the first manifestations of the Institute's spirit was *Hormigón y Acero* magazine, which even began to be published a few months prior to the formal constitution of the Institute. Edited by Eduardo Torroja and Enrique García Reyes, both civil engineers, it defined itself as the organ of expression for the Institute, an indispensable factor to understand the activities of both organizations. Its scientific character makes it stand out among the other Spanish construction journals of its day.

Between May 1934 and June 1936, a monthly magazine was published in Madrid with the title *Hormigón y Acero. Revista técnica de la construcción.* Its publication was abruptly suspended due to the start of the Civil War in 1936, but its 26 issues represent possibly one of the most brilliant and unique experiences in terms of collaboration between architects and engineers, both inside Spain and abroad.

Its structure included a novel and highly specialized "*Sección de Instalaciones*" that began in issue number 9 from January 1935. Aware of the growing importance and, at the same time, the scant treatment given to certain topics in the technical literature on construction, this new section attempted to respond to "issues of

NÚMERO DEDICADO AL CONCURSO DE PROYECTOS DEL HIPÓDROMO DE MADRID

HORMIGON Y ACERO

INDICE DE MATERIAS

NUM. 7 · NOVIEMBRE, 1934

S. E. PURICELLI - pavimentos para toda clase de tráficos - manuel silvela 1 - tel. 31538

Figure 9. Issue 7 of the magazine *Hormigón y Acero*.

great importance that, in general, are not considered or are not dealt with specifically with the interest they represent for architects and builders" by covering such topics as the building's installations and the complementary or auxiliary resources used in the organization of an engineering or architectural project. It discussed questions dealing with heating, cooling and air conditioning, thermal and acoustic insulation, electrical installations in general, lighting or other domestic uses of electricity, such as, for instance, the first article published in this section, entitled "*Las aplicaciones de la electricidad en la vivienda moderna*", or the three relevant texts published in 1935 by the aforesaid architect Manuel Sánchez Arcas on natural light, as a consequence of the lectures taught in a course on this subject at the same time in the Institute. As a complement, the section devoted one or two pages in each issue to information from commercial companies on ancillary resources such as modern machinery, measuring instruments, materials, or patents, to mention just a few of those reviewed in the journal.

3 THE PERMANENT BUILDING EXHIBITION AND INFORMATION CENTRE, CEIPC, 1934–1936

Following the example of the Americans, permanent exhibition and information centres began to open in the European countries within a period of a very few years between 1929 and 1935.

The *Centro de Exposición e Información Permanente de la Construcción* CEIPC (Permanent Building Exhibition and Information Centre), of Madrid was opened in 1934, promoted by Mariano García Morales with the collaboration of the architects Mariano Garrigues and Manuel Sanchez Arcas.

The centre provided a permanent and free information service with respect to building materials and a place where building technicians could meet and exchange know-how and ideas. It did not sell or represent the products on show; all it did was provide impartial information about them. In January 1935 CEIPC published the first issue of its monthly magazine *RE-CO, Referencias de la Construcción* (Building References), the first of 17 published up to May 1936.

Between 1934 and 1936 the *Centro de Exposición e Información Permanente de la Construcción* (CEIPC) in Madrid played a similar role to that of the Bauwelt Musterschau of Berlin and especially to that of The Building Centre in London, with which it maintained a close relationship.

This is reflected by the magazine *RE-CO* in which articles translated from English were published. It also sent a correspondent to report on the trade shows organized by the building industry, especially those featuring new materials and the incorporation of new technologies.

The work carried out by the centre had a great influence in a short space of time (just over a year and a half). The courses and series of conferences it organized set out to inform about innovations in the building industry. For example, the subjects examined during one of these series, which the public attended in droves, included: the use of ribbed metal and lightweight profiles in the building process; the application of electricity in the modern house; autogenous welding in the building industry; the electrical incandescent lamp; asbestos-cement pipes; the problems created by the telephone in the building process; metallurgy in the construction of modern buildings; the use of linoleum in the building process; the current importance of sanitation services in Spanish housing; the modern capabilities of lifts and the heat insulation of buildings and of domestic heating appliances.

4 FINAL THOUGHTS

In the context of the fruitful collaboration between the group of Madrid-based architects and civil engineer Eduardo Torroja, Manuel Sanchez Arcas' work reveals a deep interest in integrating technique and architecture.

In little over 10 years, several of the most brilliant contributions of modern Spanish architecture were made within a context marked by the search for a new architectural idiom and the use of new materials, above all reinforced concrete, within the development of modern architecture.

It is important to stress that although it was Eduardo Torroja's know-how that made the realization of some of these projects possible, it was precisely when he was collaborating with architects the likes of Zuazo, Sánchez Arcas, Arniches and Martín Domínguez that Torroja did his best work.

The most decisive fact in his career, was without doubt his incorporation in 1929 as an engineer on the team of the *Junta de Construcciones de la Ciudad Universitaria de Madrid*, overseen, from 1928, by Modesto López Otero as Lead Architect, and a design team led by the young architects Miguel de los Santos, Agustín Aguirre López, Luis Lacasa, Manuel Sánchez Arcas and Pascual Bravo. Torroja worked alongside all the architects on the team designing the Ciudad Universitaria, but his collaboration with Sánchez Arcas represented a decisive watershed, marking a turning point in their careers.

The collaboration between Sánchez Arcas and Torroja was more intense and prolonged in time than with other architects. In addition to the buildings constructed on Ciudad Universitaria complex (Hospital Clínico, Pabellon de Gobierno, and Central Termica), they worked together on the Algeciras Market and on the unconstructed project for the Competition for the San Sebastian Hospital. All of them show a real interaction between architecture and technique, which is necessary to emphasize.

Of the group formed by Zuazo, Arniches, Domínguez, Sánchez Arcas and Torroja, with the exception of Torroja, all were disqualified by Franco's regime from practising as architects after the Civil War. It is difficult to know what would have happened if that collaboration had not been so traumatically interrupted, but all the signs point to their having left a legacy of even more exceptionally interesting works.

In the fullness of their mutual collaboration, they sought the architectural expression of new materials in the early days of modern architecture and, in addition to their unquestionable individual talents, they were also the children of an extraordinary age for educational and scientific advancement in Spain. They were trained under the influence of the *Junta de Ampliación de Estudios e Investigaciones Científicas*, JAE. Founded in 1907 and presided over by Santiago Ramón y Cajal from then until his death in 1934, the Board set itself the task of promoting scientific research and education, and of trying to attain the level of science, technology and culture they saw in other modern countries.

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History of Construction Cultures – Mascarenhas-Mateus & Paula Pires (eds)

TRABEKA – General contractor in Africa and Belgium (1924–39)

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ABSTRACT: The TRABEKA company is a colonial general contractor that began its activities in Katanga in 1924. Its business in concrete construction rapidly grew till 1929. In order to cope with the shortage of works resulting from the economic crisis, the company expanded its activities in the 1930s in Africa, Iran and Belgium. In Belgium, it succeeded in building several apartment buildings with well-known architects in Brussels and in developing a strong regional branch in Liège for engineering works. This paper, based on original research work in archives, is limited to the company's pre-war period of construction activities in Congo until 1955 and in Belgium till 1959.

1 INTRODUCTION

Among the actors in the construction industry, contractors have received the least attention in the research on construction history. This is due to the fact that these companies often disappear as a result of liquidation, merging or bankruptcy, which usually leads to the destruction of the company's archives. Another cause is the lack of interest by contractors or engineering offices to keep archives and documented records of their business beyond what is legally enforced (10 years). This is, unfortunately, the common situation in Belgium.

With this article, we begin to write the history of the Belgian-Congolese colonial construction company TRABEKA (Travaux en Béton au Katanga, abbreviated hereafter TBK), created in 1924 in Katanga, initially to serve as an outlet for the production of cement by its parent company, the CIMENKAT cement factory in Lubudi. TBK remained mainly focused on works in Katanga until 1929, then, in the 1930s, it extended its activities to other African countries, as well as Iran and Belgium. It continued its construction activities in Congo until 1955 and in Belgium until 1959. Generally speaking, colonial construction companies in Congo have so far received even less attention from researchers than construction companies in Belgium. The existing archives of the TBK, deposited in the State Archives in Belgium, allow, for once, a rather thorough and interesting study of the history of the company. The richness of these archives only allows us to deal here with the first part of the history of this company, up to the eve of the Second World War.

2 TRABEKA'S LEADERS


Figure 1. Victor Brien in the late 1920s (ULB Archives).

Victor Brien (1876–1959) was the founder and leader of TBK for many years (Figure 1). Of modest origins, he graduated as a mining engineer from the University of Liège in 1900 and as a geological engineer in 1902. In 1900, he joined the state Corps des Mines, which had already led him to carry out geological missions in Congo (Stockmans 1971). His expertise and scientific publications (Sluys 1960) led him, in 1910, to become Professor of Geological and Mining engineering at the Université Libre de Bruxelles, a chair he held until 1937. In 1911, he left the Corps des Mines and also became consulting engineer for SIMKAT (Société Belge Industrielle et Minière du Katanga, founded in 1910) where he worked for more than 35 years.

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He established the research and development programme of this company and its subsidiaries: CIMENKAT (Ciments du Katanga) founded in 1922; TBK founded in 1924; and SERMIKAT (Société d'exploitation et de recherches minières au Katanga) also founded in 1924.

TBK has to be considered as a subsidiary of CIMENKAT which, through the various capital increases, would always retain around 35% of TBK's shares. The other two main shareholders of TBK are SIMKAT for about 10% and Belgo-Katanga for 3%. The remaining shares, a little over 50%, were originally held by about 20 registered shareholders, Victor Brien, himself, being the most important of these private shareholders. He was also one of the representatives of SIMKAT and CIMENKAT on the Board of Directors of TBK. Victor Brien was Managing Director (Administrateur-Délégué) of TBK from 1924 to 1935, Vice-Chairman of the Board of Directors from 1935 to 1946, Chairman of the Board of Directors from 1946 to 1955, and finally Honorary Chairman from 1955 until his death in 1959.

The Board of Directors consisted of six to eight members. The names of most of the directors are well known in the history of the administration of colonial companies. Maurice Auguste Lippens (1875–1956), Honorary Governor General of Congo (Ranieri 1997; Van der Straeten 1968b), was the first chairman of TBK from 1924 to 1925. Gaston Périer (1875–1946) (Van der Straeten 1958a) then held the presidency for some 20 years before handing it over to Victor Brien. Among the directors, the following should also be mentioned: Lucien Beckers (1880–1959) (Stockmans 1983), member of the Board from 1925 to 1955; Arthur Bemelmans (1881–1952) (Van der Straeten 1968a), member from 1927 to 1952; Jules Cousin (1884–1965) (Emmanuel 1968), member from 1927 to 1959; Louis Goffin (1861–1927) (Coosemans 1948), member from 1924 to 1927; Edgar Sengier (1879–1963) (Jaumotte et al. 2016; Van der Straeten 1973), member from 1932 to 1955; Adolphe Stoclet (1871–1949) (Lavachery 1965), member from 1932 to 1941. All of these directors are related either to CCCI, the Compagnie du Congo pour le Commerce et l'Industrie, i.e. ultimately Société Générale de Belgique, or to UMHK, the Union Minière du Haut Katanga. Lippens and Périer are jurists, but all the other personalities on this list are engineers by training with solid overseas field experience. Georges Touchard (1874–1948), a jurist (Van der Straeten 1958b), also linked to the CCCI, was chairman of the finance review committee from 1924 to 1948.

After Victor Brien stepped down in 1935, the position of Managing Director was entrusted successively to two engineers who had been directors of TBK in Africa: Edgar Larielle (1890–1953) (de Magnée 1968), then Henri Vander Borght (1890-?) from 1953 onwards.

The official head office of the colonial company TBK was located in Elisabethville (Lubumbashi), but the administrative head office was in Brussels, where the Board of Directors and the General Meeting of the shareholders had their meetings.

3 SOURCES FOR STUDYING TRABEKA

We are indebted to Jean-Louis Moreau for having indicated to us in the archives of the CCCI (Brion et Moreau 2006) and the Société Générale de Belgique (Brion et Moreau 2005) deposited at the Belgian State Archives, the files specifically related to TBK. They are, in fact, professional archives of Directors of TBK linked to CCCI and to the Société Générale de Belgique. Their examination led us to consult in particular:

- a series of 13 reports entitled 'Notes documentaires' prepared for the members of the Board of Directors, 9 of which were drawn up between 1928 and 1938, and 4 of which were drawn up between 1950 and 1972; these reports, which are classified as confidential, are typed in a limited number of copies: the copies are numbered and, in some cases, are illustrated with photographs;
- a series of 45 printed and published 'Fascicules' containing the reports of the Board of Directors and the annual accounts presented to all ordinary and extraordinary general meetings of the shareholders from 1925 to 1972;
- minutes of meetings of the Board of Directors from 1929 to 1945 (with gaps), from 1954 to 1955 and from 1958 to 1959.
- an illustrated and published catalogue of TBK's achievements up to 1930 (Catalogue ca 1930).

In addition, we had previously discovered four reports by TBK on its achievements in the field of bridges and dams, published in or around 1940 (Coppée 1940a; Coppée 1940b; Trabeka ca 1940a; Trabeka ca 1940b), probably for prospective clients. Other sources of documentation are published articles on TBK's achievements in Belgium and Congo.

The archives that have been consulted are, therefore, mainly of an administrative and financial nature. For example, there are no calculation notes and no drawings of constructions carried out by TBK in Africa or Iran. The ULB archives contain one file relating to Victor Brien and another relating to the construction of his country house in Lembeek.

4 1924–31: EVERYTHING HAS TO BE BUILT AND EQUIPPED

TBK's activity began in October 1924. It began with the construction of a workshop for the prefabrication of concrete elements (hollow blocks, ornamental blocks, slabs and tiles, window frames) in Elisabethville (Lubumbashi) (Figure 2). The workshop was operational in 1925, and its production was extended to include other products such as concrete railway sleepers, pylons, pipes, and safes. The workshop was very active until the end of 1929, at a time when the world economic crisis was beginning to be felt, particularly in Congo. From 1930 onwards, the workshop's activity was very reduced. In 1929, TBK started the construction of a factory for the production of fibrocement elements (corrugated sheets) adjacent to the CIMENKAT cement factory in Lubudi. The factory was commissioned in July 1929 and had to be shut down in May 1931 due to a lack of outlets for its products.

TBK's first major industrial customer was the UMHK for its Panda facilities near Likasi. TBK carried out major works there from 1926 to 1928, then from 1930 to 1931 (Figure 3). From 1927 to 1930, TBK carried out, for Sogéfor (Société Générale des Forces Hydro-électriques du Katanga), the important hydroelectric development works of the Cornet Falls in Mwadingusha, including the construction of a concrete dam 8 m high and 550 m long (Bette 1931) (Figure 4). This development was intended to produce the electrical energy required for the refining activities of the UMHK in Panda (Trabeka ca 1940b).

But TBK does not limit itself to major civil engineering works: in Katanga – Lubumbashi and Likasi mainly – it carries out numerous concrete works for the erection of private civil buildings (office buildings, hotels, shops, banks), public buildings (courts, town halls, schools, customs warehouses (Figure 5), and railway stations) and churches (Figure 6), as well as buildings and equipment for industry (breweries, slaughterhouses, laundries, flour mills, coal mines, sheds, etc.) (Trabeka ca 1930).

TBK was also very active in the field of housing construction, be it houses for European expatriates or housing quarters (Figure 7) for indigenous workers, located near mining operations or industrial installations; TBK used its prefabricated, concrete or fibre cement products intensively for this purpose. This was

Figure 2. The prefabrication workshops in Lubumbashi, ca 1928 (Trabeka ca 1930).

Figure 4. Concreting the gravity dam at Mwadingusha in 1928 (Note documentaire 2 1929).

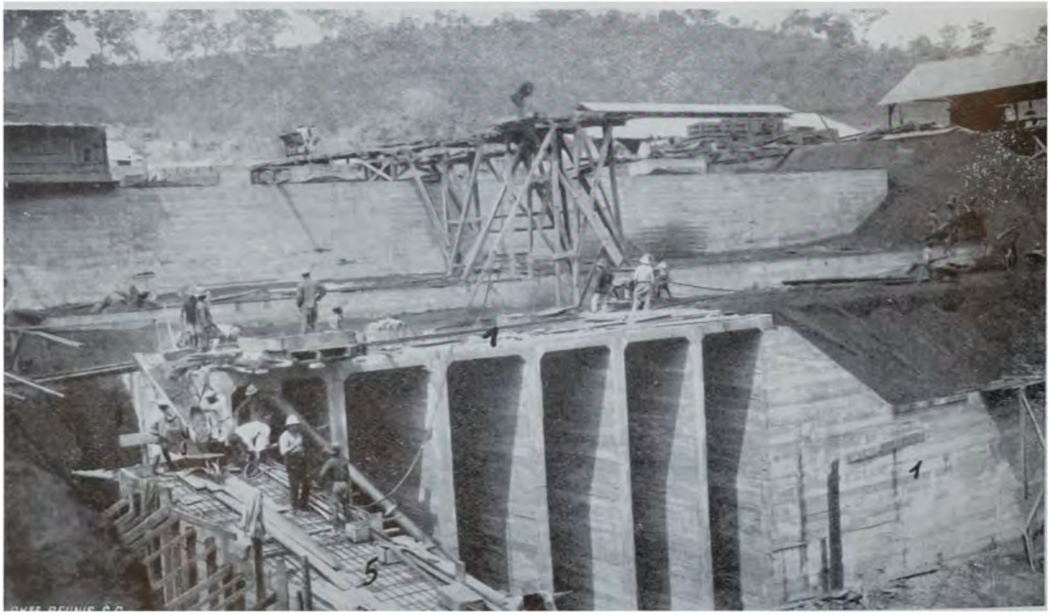

Figure 3. Concreting the foundations of the drying unit of UMHK installations in Panda, ca 1928 (Trabeka ca 1930).

particularly the case for the Mufulira mining complex in Northern Rhodesia (Zambia) from 1929 to 1930, where TBK even set up a prefabrication workshop for concrete products (Trabeka ca 1930).

TBK started developing concrete roads in towns as early as 1930 and also carried out sewerage and drainage works. The bridges built by the company during this period are few in number and of small span, with the notable exception of a 48 m span "Vierendeel" type bridge built in 1931 to cross the Lufira River on the road between Lubumbashi and Likasi (Trabeka ca 1940a) (Figure 8). The bridge was built on behalf of the government (Devroey 1939; Devroey 1944). It may well be the largest "Vierendeel" type road bridge in reinforced concrete ever built if one does not count the 56 m span footbridge erected in La Louvière (Belgium) in 1911.

Seeking to expand its activities outside southern Katanga from the late 1920s, TBK carried out major works in 1930–31 at the port of Albertville (Kalemie) on the west shore of Lake Tanganyika, where it built a slipway, a dry dock and various industrial constructions (Coppée 1947; Trabeka ca 1930). In Bas-Congo, in 1931, TBK carried out the hydroelectric equipment of the Inkissi Falls in Sanga on behalf of the Société des Forces Hydroélectriques de Sanga (Trabeka ca 1940b).

From an organisational point of view, TBK had administrative services, design offices and drawing offices at its headquarters in Congo. But it also had central administrative and financial services in Brussels, shared with the other companies of the SIMKAT group, as well as a technical design office, the management of which it had entrusted to René Coppée, a civil engineer who had graduated from Ghent University in 1920 and was hired by TBK at the end of the 1920s.

5 1932–39: GEOGRAPHIC DIVERSIFICATION

Apart from the first two financial years (1924, 1925), the company's turnover and profits rose steadily until

Figure 5. Church in reinforced concrete under construction (1930) in Lubumbashi (Trabeka ca 1930).

Figure 7. Full concrete houses for native people, built in 1928 in Lubumbashi (Trabeka ca 1930).

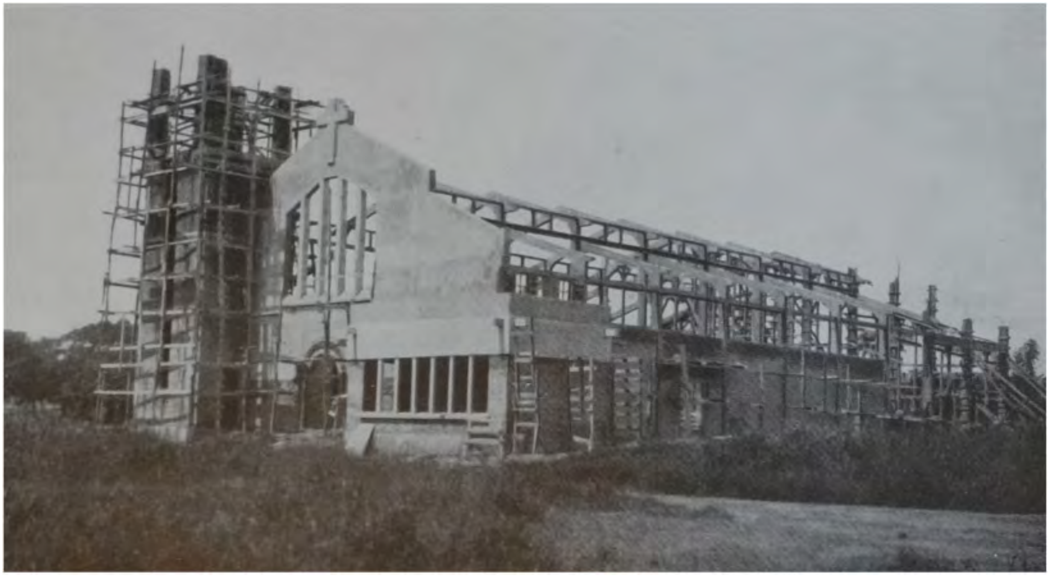

Figure 6. Customs house in Lubumbashi, 1928 (Trabeka ca 1930).

Figure 8. 48 m span concrete "Vierendeel" type road bridge built in 1931 over the Lufira River, still resting on its centre (Belgian State Archives).

1931. At the end of 1930, the staff employed directly in its offices in Africa and on its building sites, including its subcontractors in Northern Rhodesia, numbered up to 3000 workers (Trabeka ca 1930) along with an expatriate staff of 116. But from 1929, and especially from 1931, the effects of the world economic crisis were very quickly felt, forcing TBK to extend its activities outside Katanga.

A first significant action was to create, in early 1932, a French subsidiary, FRABELTA (Société Franco-Belge d'Entreprise de Travaux en Afrique), renamed shortly afterwards FRACOLTRA (Société d'Entreprises et de Travaux en France et aux Colonies) officially located in Paris, enabling TBK to bid for works in the French colonies in Africa and to also consider works in France. Not only was the capital of this company almost entirely controlled by TBK, but the actual management and studies of this subsidiary were carried out by TBK in Léopoldville (Kinshasa) and Brussels. This French subsidiary soon obtained contracts for earthworks and small engineering structures for the Congo-Ocean railway line between Pointe-Noire and Brazzaville. This colonial construction company (1921–34), with a sinister memory for the harsh working conditions of the indigenous labour force, was characterised by a very high mortality rate, particularly before 1930. FRACOLTRA intervened here rather late from 1932 to 1933 when the works were nearly finished. The company also carried out concrete construction work in Pointe-Noire (1934–36) and Brazzaville (1936–37).

FRACOLTRA studied and submitted tenders for the execution of works for numerous projects in Morocco, Algeria, Dahomey (Benin) and Madagascar but did not win any despite the association for some of them (bridge in Algeria, dam in Madagascar) with Henry Lossier (1878–1962), a highly respected design engineer. The only exception was the awarding of a contract for the construction of a multi-storey shed and some work in the harbour of Tamatave (Madagascar) carried out in 1934–35. In 1936, the company FRACOLTRA was put on hold and was finally dissolved in 1948.

TBK also tried to explore other markets in Africa, with the construction in 1933 of a bridge over the Kowie River at Port Alfred (South Africa) (Trabeka, ca 1940) and an underground reservoir at Bulawayo in Southern Rhodesia (Zimbabwe), but these deals turned out to be loss-making.

Also in 1932, the Bécarco design office (Bureau d'études de construction et d'architectures coloniales) was created in Brussels under the direction of R. Coppée. This enabled TBK's engineering office in Brussels to work for all the companies of the SIMKAT group and the partners of the founding shareholders' union at the strict cost price of the studies. They were also able to propose the know-how of the engineering office for new clients as a new activity. This was directly used to carry out the studies for the works obtained by FRACOLTRA, a shareholder for one of the 20 shares of Bécarco (TBK owned nine).

A successful geographical diversification of TBK was the enterprise in Iran from 1935 to 1938. In equal association with the company SOCOL (Société continentale et coloniale de construction), TBK carried out the works of a section (lot 11) of the Transiranian railway linking the Caspian Sea to the Persian Gulf as well as a long road tunnel under the Alborz Mountains. Section 11 of the Transiranian line, located in the mountainous area north of Tehran, was only 19 km long, but included 13 tunnels with a total cumulative length of 7500 m (the longest being 1430 m) and 7 viaducts, two of which were 30 m high and more than 100 m long (Trabeka ca 1940a). Further west, the road tunnel (single lane) is located at 2700 m altitude under the Kandovan Pass and is 1850 m long. This tunnel was widened to two lanes in 1995–2002 (Atretchian 2005). At the end of 1936, 191 technical and administrative expatriate agents and 2710 Iranian workers were employed in this undertaking which was very important, both in terms of work volume and as a financial venture. While other contractors on other lots of the line, such as the Belgian company CFE (Compagnie de Chemins de Fer et Entreprises), were incurring losses, Larielle, in an analysis dated 1944, attributes TBK's financial success in Iran to a practice of moderate bidding discounts and strict on-site control of the quantities of cement in the concrete batching, according to the specifications and the volumes of concrete used for the tunnel linings.

In Congo, TBK had very few business opportunities between 1932 and 1935. The company built spillway dams for the hydroelectric developments of the Luvua River Falls 80 km from Manono in Katanga from 1931 to 1932 (Trabeka ca 1940b) for the Géomines Company. In 1932, TBK also carried out some concrete surfacing works (roads, canal linings) in Léopoldville (Kinshasa). The only undertaking of any importance is the construction in 1933–34 of a 96 km long road in the Kibara Mountains, enabling SERMIKAT to transport the tin ores extracted from its mines to the Lualaba River. This road required the construction of 14 bridges (Trabeka ca 1940a). At the end of 1935, TBK employed only nine European agents and 107 indigenous workers in Congo: the gross profits of the company, including its construction sites outside Africa, had fallen to a quarter of what they were at the end of 1931.

But business in Congo began to pick up again from 1936 onwards: it was marked by an increase in activity in Bas-Congo, with concrete road surfacing in Léopoldville (1936–38), and work for various industries in Matadi, Ango-Ango (1936–40) and Léopoldville (1937–39), where TBK also built the East railway station (1939). TBK was also developing an activity with headquarters in Usumbura (Bujumbura, Burundi) where the company carried out (1937–39) important harbour works (Coppée 1947).

In Katanga, TBK carried out a hydroelectric scheme for SERMIKAT, in 1936, to exploit the energy from the M'Bale River Falls in the Kibara Mountains, with a dam 54 m long and 8.5 m high (Trabeka ca 1940b). The company also built a 150 m high chimney for the UMHK in Lubumbashi in 1937. But it is worth mentioning, above all, the construction (1937–39) of two large railway bridges for the CFL Company (Compagnie des Chemins de Fer du Congo Supérieur aux Grands Lacs Africains), obtained by TBK after a very competitive international call for tenders. These are the 495 m long 14-span viaduct at Kongolo over the Lualaba River (Coppée 1940a) and the three-span bridge over the Lukuga River (Coppée 1940b). In both bridges, which are continuous structures, the largest span is 70 m long. We have already had the opportunity to detail (Espion et al. 2015) the remarkable characteristics of these two structures which made them landmark bridges of international stature at the time of their construction. In December 1938, TBK employed 284 workers for the construction of the bridge at Kongolo, supervised by 15 European agents, and, at the bridge over the Lukuga River, 130 workers were supervised by six European agents. Finally, the last major work carried out by TBK in Africa before 1940 was the raising in 1938–39 of the Sogéfor Dam at Mwadingusha, the maximum height of which was increased from 8 to 12 metres (Bette 1941; Trabeka ca 1940b).

At the end of 1939, TBK employed 26 European expatriates and 428 African workers in Congo.

6 TRABEKA IN BELGIUM 1934–39

The most important and lasting diversification was undoubtedly the creation, in November 1933, of a business branch in Belgium. TBK, faced with a shortage of business in Africa but wanting to maintain its operational capacity and retain the best elements of its staff, which it had had to repatriate to Europe, decided to prospect the construction works in Belgium. It entrusted the management of this new division to one of its engineers who had returned from Africa, Émile Robert, a civil engineer who had graduated from the Université Libre de Bruxelles in 1923. The latter remained at the head of TBK's activities in Belgium until their cessation in 1959.

The Belgian division very quickly obtained contracts for two civil engineering projects: the raising of the embankments of the Mons to Condé canal, and the 6th lot of construction works of the Eben-Emael Fort near Liège, both executed in 1934. There followed 19 bids, studied in 1934, for public works that did not bring in any orders. This obviously testifies to intense competition between contractors in Belgium.

At the Brussels World Fair in 1935, TBK built several pavilions, including the Pavillon des Sociétés Coloniales by architects René Schoentjes (1891–1949) and Douret, the Planetarium by architects Charles Van Nueten (1899–1989) and Maurice Keym, and the Alberteum Aedes Scientiae by architects Adrien (1878–1940) and Yvan Blomme (1906–1961) (Blomme 2004). TBK's participation in the capital of the Alberteum Company and its construction would prove to be a very bad financial deal for TBK, which was never paid for its work.

From 1935 onwards, TBK developed an important pole of activity in the Liège region with works to improve the Meuse River between Ivoz-Ramet and Jemeppe-sur-Meuse on behalf of the Ministry of Public Works, including dredging, embankment and bank works. This job lasted until 1939. This was accompanied by works to build water intakes and

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Figure 9. Advertisement for the sale of premium apartments (Fondation CIVA).

pumping stations for industrial companies along the river in Seraing (1936) and Flémalle-Haute (1936–37) and the laying of sewer networks (1937–38) as part of the extensive works undertaken by the Association pour le Démergement de la Meuse (currently AIDE).

In Brussels, TBK, like other contractors, began to develop premium apartment building projects, a market that became fashionable in the 1930s. TBK did so here successfully with recognised architects. The company built in this way:

- in 1935, a double building at 7 Rue Forestière and at 42 Rue de Tensbosh (Flouquet 1936) with architects A. and Y. Blomme;
- in 1936, a building at 72 Avenue de l'Hippodrome (Culot et al. 2012) with architect Jean-Jules Eggerickx (1884–1963);
- in 1936–37, a building at 202 Avenue des Nations (Blomme 2004), now Avenue F.D. Roosevelt, with architects A. and Y. Blomme;
- in 1938–39, a building at 25–26 Avenue de la Cascade (N.N. 1939), now Avenue Général de Gaulle, with architect Jacques Saintenoy (1895–1947) (Figure 9).

And, Victor Brien naturally entrusted TBK, in 1937, with the construction of his country house in Lembeek (south of Brussels), according to the plans of architects A. and Y. Blomme. It is a vast estate, designed as a forestry and agricultural development, whose construction would last until 1940. Brien donated this property, now known as "Lembeek Castle", by will to the Université Libre de Bruxelles, which is still the owner.

In mid-1938, the Belgian division of TBK had a staff of 22 employees – engineers, draughtmen and administrators – and 397 workers, 347 of whom were employed by the Liège group alone.

TBK carried out bathing installations in Knokke – a resort on the Belgian seacoast for the Compagnie Immobilière du Zoute, in 1936, various works for the Raffineries Tirlemontoises company (1938–39), and 300 m of culvert for the 4th section of the Senne covering in Brussels (1938–39). After the outbreak of war in Europe but before the invasion of Belgium, TBK built a gas protection shelter at the North-South railway junction in Brussels and military shelters in the Antwerp region in the autumn of 1939.

7 CONCLUSIONS

This study of the first phase of the TBK's existence revealed a company:

- which began its activities in Katanga in 1924 and grew rapidly until 1929, during the early period of development of industrial and mining exploitation in this rich mining region. TBK does not seem to face any serious competition and enjoys a de facto quasi monopoly;
- which sells construction materials and products, builds housing and carries out industrial construction of public buildings and civil engineering works;
- which is innovative, in particular through the introduction of concrete roads;
- which, as soon as the world crisis made itself felt around 1930, sought with varying degrees of success, to diversify geographically by relying on the skills and mobility of its engineers; this diversification resulted in a major success in Iran and, despite strong competition, the establishment of a profitable division in Belgium in the 1930s, particularly in real estate development in Brussels and civil engineering near Liège;
- which, when activities in Katanga were resumed, quickly regained a foothold there and built two very remarkable bridges according to the international history of bridge engineering;
- which was remarkably managed by its founder, Victor Brien, and the members of its Board of Directors, as reflected by the fact that during its first 15 years of existence (except in 1924–25), TBK was always profitable and distributed a dividend to its shareholders, even during the great economic crisis.

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The Ghent Booktower (1933–1947): A product of collaborating professionals within institutional know-how

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ABSTRACT: The Booktower complex, the central library of Ghent University (1933–1947), is a celebrated masterpiece of modernist architect Henry van de Velde. In addition, the tower also counts as one of the first European towers in reinforced concrete, next to several other noteworthy structural and technical achievements. This paper revisits the process of designing and building the Booktower, evaluating the architect's collaborations with engineers including Gustave Magnel and Jean-Norbert Cloquet but also the contributions of skilled contractors like Gillion and Van Pottelbergh, specialists in the use of reinforced concrete. This paper scrutinizes the collaborations in the design team by assessing contracts, plans, correspondence and other archival materials. The research develops a rich perspective on the respective roles of architects, engineers and contractors, demonstrating how their collaboration was largely conditioned by the university and how each came up with state-of-the art methods to meet the challenges of the project.

1 INTRODUCTION

The Booktower (translated from the Dutch "Boekentoren," meaning tower for books), the building for the central library of Ghent University, is a landmark building which has been in the regional news on several occasions over the last few years. In October 2020, the tower served as "canvas" for uplifting messages projected by Ghent University, owner of the tower, to support the students and citizens of Ghent during Covid quarantine (Schouppe 2020). The recent renovation and extension of the library, including the addition of an underground book depot and the restoration of the original concrete façade, has also brought the tower into public attention.

This paper is part of the Ph.D. research of the author aiming to deepen insights into the professional collaboration between architects, engineers and contractors throughout the long 20*th* century in Belgium. This historical research considers collaboration in building as an essential strategy to harness the collective knowledge of individuals to achieve better results, enabling them to cope with the growing complexity in building technology (Carraher & Smith 2017). The research sets out to determine the historical cultures of collaboration in building in Belgium.

This paper critically assesses authorship in designing and building, often solely attributed to the architect then seen as a lone genius (Sawyer 2017). The paper starts with the finding that this is the case in the professional and public reception of the Booktower, labelled as a masterpiece by architect Henry van de Velde (1863–1957) in all monographic references (Föhl et al. 2013; Hollis 2019; Ploegaerts 1999; Ploegaerts & Puttemans 1987). This research does not intend to diminish the importance of Van de Velde's work but rather considers it part of a more complex process of designing and building. This aims to reveal the contributions of the central actors and to investigate the importance of the knowledge and inventiveness of engineers and contractors. Thus, this case study seeks to highlight the Booktower's building history as a "shared history" of architecture, engineering and construction.

Scrutinizing historical collaboration in designing and building is a challenging endeavour. The act of collaboration, its quality and extent, even its consequences, are difficult to detect and to identify. Collaboration, as most human interaction, is intangible and the few paper traces left for historians are tricky to interpret (Pressman 2014). This paper wants to show that complex buildings are shaped not only by ideas or materials, but also by actions and interactions between the building professionals. Some reflections of these human interactions can be found on paper in the form of alterations to plans, in written correspondence which refers to conversations, meeting reports, construction diaries, and so on. Therefore, crossing archival material from different actors allows, at least partially, to reconstruct a story of collaboration.

The Booktower is, because of its programme and because of its administrative and technical challenges, a complex building. The intertwining of interests between the Belgian state, the university as an institution, the users and the building actors also makes it a specific case in point. Secondly, the contract between

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the designers and the client (the ministry of education) seems rather unusual to contemporary Belgian standards. This contract fixed the designers who were to collaborate on this project and was signed by architect Henry van de Velde (1863–1957), and engineers Gustave Magnel (1889–1955) and Jean-Norbert Cloquet (1885–1961), all professors at Ghent University. Thirdly, historical work on the Booktower is manifestly incomplete and notwithstanding its recognition as a masterpiece, the building did not receive much detailed attention, not even in extensive monographs on Van de Velde (Ploegaerts & Puttemans 1987).

Consequently, archival research forms the basis of this research. The original building files, compiled by the then head librarian René Apers (1888–1976) who collaborated intensively with Van de Velde to optimize the economics of the library, are kept in the Booktower archive and are accessible. Another source consulted is the "Fonds Henry van de Velde", kept by the family, which contains a limited amount of plans and a whole collection of correspondence concerning the Booktower. The aim was also to consult the archives of the engineers Magnel and Cloquet, kept at the Archives of Ghent University, but this was impossible due to Covid restrictions.

After observation of the building procedures and of the many actors from the first design to the completion of the building, this paper considers only the design and execution of the structure and the envelope of the building. The tendering procedures for the interior and the large amount of furniture (book cases, tables and offices) will not be assessed.

2 THE INTERWAR BUILDING CAMPAIGN OF GHENT UNIVERSITY AND THE LEGAL FRAMEWORK

From 1932 onwards, Alfred Schoep (1881–1966) was administrator-inspector at Ghent University, guarding the interest of the Belgian state (Ghent University was a state institution) and in charge of the university's spatial requirements (Desmet 1943). His appointment came only a few years after two important changes in national law, giving leeway to a new building campaign for universities. The first law impacting higher education was enacted in 1928 and put an end to the ambiguous relation between the city of Ghent and the university as instated in 1835. From 1928 onwards, the city was no longer responsible for the built patrimony of the university (Meganck 2002). The second law, issued in 1929, installed several new degrees at the university, demanding more (and new) practical experimentation and technical laboratories (Cloquet 1937). As these new schools and institutes needed new spaces and because the industrial activity that was located near the Blandijnberg had shortly before moved to the north of the city (closer to the docks) the former site of Feryens, a flax spinning company, seemed an optimal site for this expansion (Debo 2014). Additionally, several worker residences were abandoned, creating an opportunity to intervene on an even larger scale.

3 THE BOOKTOWER CONTRACT AND PRIOR COLLABORATIONS

Particularly interesting to understanding the collaboration in the case of the Booktower is the initial contract between the "client", Minister of Public Education Victor Maistriau (1870–1961), and the design team. This document was signed on June 20th 1934 by three parties for the designers, sharing responsibility. The team consisted of architect Van de Velde, "Ingénieur Architecte" (engineer-architect) Cloquet and "Ingénieur Civil des Constructions" (civil engineer) Magnel. The contract stated that Van de Velde was responsible for the architectural plans. The measures, specifications and the tendering procedures were left in the hands of Cloquet. The contract explicitly stated that the architects were to "commit themselves to ensure the artistic direction" pointing to Van de Velde (HS.III.128.01.01 1934). They were allocated honorary fees with a distribution of two thirds for Van de Velde and one third for Cloquet (on all executed works). Magnel, acting as the structural engineer, received a honorarium of only one tenth of the total cost of the concrete works, even though he had far-reaching responsibilities as far as these concrete works were concerned. He was not only responsible for the calculations, measurements and specifications, he also had to write technical reports and check contractor calculations for formwork and reinforcements.

It is important to note that this rather unusual contract was signed when Magnel and Cloquet, both with the Technische Scholen (Faculty of Engineering), were already engaged in two other major building projects for the university. Consequently, they had prior experience in collaborating, both together and within the university's structures. Both professionals were involved in the project for the Technicum (1932–1938, design; 1934–1954 execution), a laboratory complex, responding to the new needs for higher technical education (Devriese 2005), and in the project for the Academic Hospital, to be located on the De Pinte Avenue at the edge of the city. For the latter, professors Armand Cerulus (1895–1991), Gommaire Van Engelen (1877–1963) and Maurice Wolters (1886–1967) were also members of the team, referred to as CAVAZ (College van Architecten voor het Academisch Ziekenhuis, or College of Architects for the Academic Hospital). (Laporte 2016) The same three experts were later appointed consultants for the electrical and heating and ventilation systems for the Booktower. The fact that most of these men worked together on different projects hints at a "sustainable" collaboration. Next to being institutional colleagues, they seemed to engage in a rather smooth, interpersonal exchange.

Van de Velde was not unknown to Ghent University either. He was appointed professor in the history of building arts at the Faculteit der Wijsbegeerte en Letteren (Faculty of Literature and Philosophy) where he taught the courses "General history of building arts" and "General history of applied arts" (in succession of J.-N. Cloquet) from 1925 to 1936. It was F. De Backer (1891–1961), chairman of this faculty, who expressed the wish to engage the then internationally famed architect and colleague Henry van de Velde to design the new university library. Van de Velde never had the chance to build a public building in Belgium before. (Baillieul et al. 1985) His old friend and Minister of Education at the time, Count Maurice Lippens (1875–1956) appointed him in 1933 as architect for the library on the architect's 70th birthday several months before the initial contract was signed.

4 THE DESIGN PROCESS

4.1 *Preliminary design*

At the time Van de Velde designed the Booktower, he had an architectural office in Brussels (1926–1947). From the start of the design process, he was intrigued by the American skyscraper and wanted to create a vertical book warehouse which, according to Van de Velde, was interesting "because the distance could be covered by an elevator, and therefore a minimum of time and effort would be needed to deliver the books to the reading rooms" (De Meyer 1991). The typology of the tower in library buildings was almost unprecedented in Europe, with the rare exception of the library of Cambridge, built in 1934 (Harper et al. 2018).

The fact that a tower was chosen was all the more spectacular on the site of the Blandijnberg, one of the highest points in the city. Van de Velde had presented three preliminary designs to Minister Lippens who ordered the architect to proceed with the tower. As the design developed further, Lippens requested a large scale model in plaster to be exhibited in the university. On this occasion, in December 1934, the general press wondered if the tower was not an undesired disturbance in the skyline of Ghent. Surprisingly, the Ghent modernist architect Gaston Eysselinck (1907–1953) was one of the fiercest critics and had architectural concerns about the presented project. He feared that "visitors will be mistaken when they want to enter the complex coming from the S.-Pieters Square, because there is no entrance there (…) the rear facade has become the front facade without an entrance" (Eysselinck 1934).

While Van de Velde stubbornly held on to the tower, and because of this criticism on the model, head librarian René Apers ordered a counter-project with professor Cerulus (professor at the Faculty of Engineering and colleague of Cloquet). The Cerulus proposal contained a book deposit 10 storeys high, shaped as an elongated volume along the S.-Hubertus street (Baillieul et al. 1985). Van de Velde reacted by making some drawings with a lower elongated volume, similar to Cerulus' plans. While Apers spent many hours discussing the project with Van de Velde, the situation suggests that it might not have been easy to collaborate with Van de Velde. Clearly, the architect had firm ideas on architecture and on how to handle "rational design", ideas which might have conflicted with the more pragmatic approach of Apers. Eventually, it took another year to reach a consensus with the final project ready in March 1936.

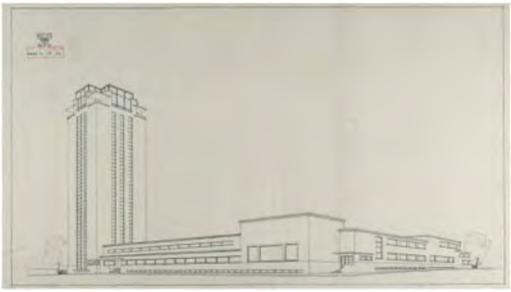

Figure 1. Perspective of the final design from the corner of the Rozier and S. Hubertus streets (1936) (Ghent University).

4.2 *Description of the building*

"Booktower" is a blanket term for two institutional entities: the central library of the university with about two million books and the HIKO institute. The library section can be recognised by the beacon of the tower with its entrance located in Rozier street. The HIKO (Historical Institute for Ancient Art) entrance is located on the intersecting S. Hubertus street. Seen from the corner of these streets (Figure 1), the all-embracing building represents a highly coherent and distinctive whole with all façades, including the tower, in exposed concrete. According to De Meyer, it is in the almost brutalist treatment of the façade that the lifelong search of Van de Velde culminates: showing the opposites between traditional values of architecture like "beauty" and the realities of modern life. Van de Velde sought a balance between such distinctions such as verticality and horizontality, between monumentality and functionality, between the urban and the human scale (De Meyer 1991). Although the function of the tower (64 m high) is to store the collection, the tall structure has windows which create not only a profile in the otherwise "flat" and "towering" walls, they also visually break the tower's massive appearance. The interplay of lines running from base to cornice emphasizes the verticality, which might otherwise look sturdy—its plan is almost square (19.5 × 18.6 m). Similarly, in the sub-structure next to the tower, the horizontality is stressed with horizontal band windows which allow for naturally lit, functional reading rooms.

The entire building is elevated in relation to both the Rozier and the S. Hubertus streets. This allows for a gentle separation between the offices of the staff and the passers-by and ensures visitors make a rising, monumental movement towards the entrance door,

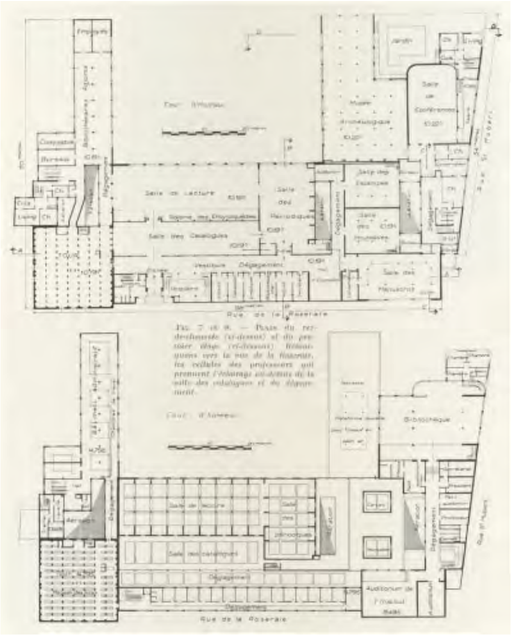

Figure 2. Plan of the ground level (above) and first floor (below) (*La Technique des Travaux*).

protected by a canopy (Figure 2). The relatively small hall gives onto the long, central corridor where the main trajectory of most visitors crosses the path of the staff. Visitors continue along the axis of the entrance and are led directly through the catalogue room, into the large reading room. This minimizes the circulation of visitors throughout the entire building and reflects the sequence of a typical visit in a direct and rational manner. The corridor, catalogue room, and a large reading room are all lit by a glazed ceiling, either providing natural light, or electrically lit. The two major reading rooms also give onto the inner-courtyard. The corridor runs along the entire length of the building and gives access to the reading room for periodicals. At the end of this long hall, the large manuscript room and smaller reading rooms for maps and special collections are located. Throughout the reading rooms, hall and corridor, the regular rhythm of the concrete structure is expressed in the detailing of the glazed ceiling and the marble floor, emphasising a uniting pattern and introducing a more human grain in the large spaces. The tower and the associated office spaces for employees are placed in a functional cluster on the opposite side of the entrance. Served and serving spaces have a clear distinction in plan. The HIKO part of the building also consists of three levels and houses all the necessary offices, auditoria, conference rooms etc. to support the well-functioning of the historical institute and its teaching activities. The most monumental room is the museum of archaeology on the first floor. After the recent renovation, this part of the building was absorbed by the central library.

4.3 *A building that breaths concrete*

While the choice of reinforced concrete for all load-bearing elements in the building was close to contemporary established practice, the proposal to also erect all façades in exposed concrete was completely unprecedented in public buildings in Belgium. While high and large-scale buildings had already been erected in reinforced concrete by the end of the twenties, certain Belgian architects still claimed that it was impossible to build high-rise buildings without a steel frame. They believed that building a tower completely in reinforced concrete posed a number of problems, with the biggest disadvantage being the dimensions of the structural elements on the lower levels (Gilles 1933). Importantly, Henry van de Velde was already familiar with working with concrete and considered it a material able to express the artistic forms he envisaged in his rational design efforts. Already in 1920, for example, he had designed the Werkbundtheatre at the Werkbund-exhibition in reinforced concrete. For the Booktower project, he could also rely on the experience of his colleague and engineer Gustave Magnel, an expert in building with reinforced concrete.

Notwithstanding its (national) novelty, several advantages in erecting both structure and façades in concrete were cited during the design phase. First of all, the speed of construction was increased. Secondly, concrete was considered a fireproof material, paramount for a library building. Lastly, the option proved to be more cost effective than a structure in steel. However, in order to attain the repetition and speed of the building process, an industrialized building process needed to be implemented. A demonstration thereof derives from the handling of the formwork and the types of contractors involved.

4.4 *Calculating the concrete tower*

In as early as July 1934, Van de Velde made an attempt to determine the dimension of the structure of the concrete tower by spacing the columns in a rational, but rather conventional manner at 4.4 to 4.4 m. This changed fundamentally when Magnel finished calculating and drawing the structure. In his article in the Belgian specialist journal *La Technique des Travaux*, engineer-architect Novgorodsky attempted to explain how Magnel proceeded (Novgorodsky 1948). The final form and spacing of the concrete columns were defined by practical and economical aspects, which appeared to be more restrictive than their resistance to natural forces being gravity and wind: the column dimensions of 0.6 to 0.2 m were defined by the dimension of two fitted bookshelves and by the dimensions of the reusable formwork, reused on all 20 floors. The result is a rather heavy concrete structure with many columns densely spaced over the entire floor, that could take the heavy book and wind loads, without beams. The limited height of the in-situ poured concrete floors of 0.09 m could only be reached by spans of 2.6 by 1.5 m (heart to heart) in the densely spaced columns. In order to appreciate the complexity of the reinforcement and the inventiveness of Magnel, we may again consult Novgorodsky. He was astonished by the ingenuity of both the calculations and the placing of the formwork by the engineer in the façade to resolve the wind load issue (Novgorodsky 1948). This demonstrates Magnel's exceptional knowledge of the material.

4.5 *Construction method*

Alongside the calculation of the general stability of the concrete tower by Magnel, the building site also required technological innovation for the two types of formwork used on the tower. Reusable formwork in metal was applied for the columns and floors and climbing formwork for the façade (of the tower). These elements were far more expensive than their wooden alternatives. It was only due to the high rate of reusability that these formwork elements became cost effective (Devriese 2005). With reusability, the speed of construction also increased as the entire elements of formwork could be moved without needing to be completely dismantled. Especially for the tower façade, the climbing formwork ensured a significant reduction in the construction time. However, it is not completely clear who exactly designed the formwork. It is likely that the Brussels-based contracting company Gillion was crucial in this process. Owner René Gillion had started the company in 1919 and it still remains a flourishing company today. Gillion constructed the Résidence Palace (arch. Michel Polak, 1923–26), Hotel Le Plaza (arch. Michel Polak, 1928–32), the NIR/INR building at the Flagey square (arch. Joseph Diongre, 1935–38), and many apartment buildings throughout Brussels (Dobbels 2018). In this period, Gillion was specialized in constructions in reinforced concrete and counted (as did other contractors) on its own engineering office. The contract between Gillion and the Ministry of Education (1936) specified that the in-house engineers of Gillion, De Brouwere and Bolouckhere, were employed. Both were graduates of Ghent University and were proficient in calculating concrete (HS.III.128.65.57 1937). Specifically about the contract, it stipulated an obligation to rely only on workers of Belgian nationality. This was an implementation of the OREC-law aimed at reviving the Belgian economy in this period of economic crisis (Vanthemsche 1982).

As the construction of the tower (1936–37) was still underway, the second venture was put to a public tendering procedure. In total, the construction of the building was organized in no less than fifteen overlapping ventures covering the period 1936–47 with all involving official public tendering procedures, resulting in the involvement of multiple general contractors. As the specifications and bids of the first three ventures (1936–38) are not in the archives it is impossible to know who competed but the rather unknown contracting company of Van Pottelbergh from the village of Erembodegem (near Aalst) won the second bid (Valcke 2003). This company had already built many churches and industrial buildings in reinforced concrete.

Figure 3. Detail of the Vierendeel trusses in the large reading room.

The commission of contractor Van Pottelbergh included the difficult task of building the large girders for the main reading room, spanning 21.3 m. Magnel had designed eight Vierendeel trusses in reinforced concrete (Figure 3), 2 m high, to allow for an almost undisturbed space and natural zenithal light for the readers. A drawing of the reinforcement bars shows the technical complexity of creating such large beams (Devriese 2005). Moreover, Magnel had published on the calculation of this type of girders, usually used for industrial buildings and bridges in steel (Magnel 1934).

The heating for the Booktower complex was provided by the central thermal power plant of the nearby Technicum (1934–38) (Baillieul et al. 1985). However, for the tower volume it was impossible to count on "conventional" water-heated radiators as the hydrostatic pressure would be too high. As an alternative, a low-pressure steam heating system was installed (Novgorodsky 1948). The interior climate of a library not only needed to be comfortable for its users and employees, but also had to take into account the preservation of the material. For this specific purpose, the Booktower had an intricate system of climatic controls at its disposal. "The air thus conveyed flows over the central battery, which consists essentially of capillary cells made of extremely fine glass wire…" (Novgorodsky 1948). Among the most remarkable technological innovations in the tower rank the different lifts. In order to provide an optimal lending service, it was important that the books were transported quickly and easily through and from the tower to the reading rooms. There is only one elevator that serves and stops at all the floors, the other six only serve every four consecutive floors. The system automatically sent out an information sheet to the desired level on which the material was located, after which the desired books were transported to the reading room via a conveyor chain. After consulting, the book was sent back to the right floor, using a pneumatic system installed by the Belgian company Moens.

4.6 *Roles of the professionals within the design process*

From the evidence found in the archives, it is clear that Henry van de Velde took on a double role in this project. From the start, Van de Velde was very engaged in the project and led the design efforts. However, when the final architectural drawings were established and all the more after construction started, Van de Velde took a step back and took on the role of artistic consultant. During this phase, Van de Velde left both Magnel and Cloquet in charge of, respectively, the design and calculation of the concrete structure and the administrative tasks (in opposition to the "creative" tasks) like the fixing and follow-up of measures, specifications, tendering procedures, etcetera. Both of these tasks show that Magnel and Cloquet had wide and thorough knowledge on the project, effectively acting as "executive" architects.

Other collaborations Van de Velde had during the same period bear witness to a similar approach. Van de Velde (in his role as advisor for the OREC) was involved with the Belgian pavilions for the World Exhibitions of both Paris 1937 and New York 1939. For the Paris pavilion, architects Jean-Jules Eggericx and Raphael Verwilghen were part of the team and for the New York pavilion Victor Bourgeois and Léon Stynen were his collaborators. Although different teams were formed, both pavilions were very similar, suggesting that Van de Velde recycled his design, but the execution of the project was placed in the hands of the respective teams. A third example is the building of the technical high-school (known as R.I.T.O.) in Louvain (1937–40) for which the complete execution was in the hands of architect Vital Rosseels. Remarkable for this project is that only one drawing can be traced back to Van de Velde, suggesting that the master relied heavily on the executive capacities of his collaborator (Adriaenssens et al. 2013).

Magnel and Cloquet can be considered "executive architects" in this case study, they took on a role of what now can be considered "consultants". Especially the role of Cloquet, who graduated in 1909 as "Ingénieur Civil des Constructions" and in 1910 as "Ingénieur-Architecte", and experienced in building practice, demonstrated that he did not contribute to any formal design decision. Moreover, in a letter to the administrator inspector, Cloquet replies more than once that on certain issues, the approval of Van de Velde is required. On behalf of Van de Velde, Cloquet was the one who prepared the necessary documents in order to execute the building and who carried out regular inspections.

The design input of Magnel, who graduated as "Ingénieur Civil des Constructions" in 1912, reached much further. As Magnel was in charge of the stability of the building, he was able to influence the architectural expression to a great extent. The tower specifically was a real challenge and as ambitious as engineer Magnel was, he seized the opportunity to reach new heights with the possibilities for reinforced concrete. Therefore, both the appearance of the façade and the plan were influenced by the design implications of the engineer. Still, Magnel complied with the pre-determined forms designed by the architect.

5 ENDURING COLLABORATION WITHIN THE INSTITUTION OF THE UNIVERSITY

During the 1930s, Ghent University set up a building campaign involving four projects: the Technicum (technical laboratories, 1934–38), the Academic Hospital (1935–54), the veterinary school (1934–60) and the Booktower. They were all part of the expansion of the university's patrimony. Under the directorship of Schoep, several technical committees were established to carry out the preliminary studies. For the academic hospital, the committee named CAVAZ counted only on professionals linked to the university. Among its members were Cerulus as the main hospital designer and Cloquet with August Desmet who both acted as administrative and consulting architects, concerned with following-up the construction phase. The designated engineers were Magnel for the structural calculations, Van Engelen for the technical installations and Wolters for the electrical installations. Most of the members were involved in all four projects that were underway. Although their involvement might be explained by their predating links with the university, their collaboration must have been successful enough in order to repetitively work together. The fact that the 1938 laboratory for reinforced concrete experimentation (block 2 of the Technicum) in which Magnel would carry out his research, was completely made out of (welded) steel (recommended by Cloquet) suggests that no pre-established preferences stood in the way of efficient collaboration.

6 ONGOING DEBATE ON THE ROLES OF THE ARCHITECT AND THE ENGINEER

In Belgium, during the 1930s, the debate between "traditionalist" and "modernist" architects found an "unequal" echo in a discussion on the position of structural design in architecture. Several architects, on both sides, championed an integration of architecture and structure (engineering), which was deemed beneficial to the conception of complex buildings. Belgium held a special position in this historical discussion as it is one of the few countries in which the degree of "Ingénieur-Architecte" existed since 1835, even if this profile was not always appreciated as can be read in architect Adolphe Puissant's fierce comment in a discussion leading up to the protection of the profession of architect: "We condemn the engineer-architect. We think (…) that both titles are antipodal and cannot be juxtaposed; we think that, by doing so, two cultures are mixed up, two absolutely different disciplines" (Puissant 1935). Jean-Norbert Cloquet also contributed to this discussion in the first issue of the periodical *L'Ingénieur-Architecte*, when he questioned to what extent the engineer-architect was able to create architecture. He argued that because of the teaching of both artistic principles and scientific knowledge, an architect-engineer was able to take a different approach to architecture. Especially in the 1930s as modern building practices and new technological means made their entry in architectural production, the architect-engineer was the desired professional to take on these challenges (Cloquet 1935). The discussion was sharpened when architectural critic Pierre Bourgeois, brother of architect Victor Bourgeois, asked the question of the problem of collaboration in the periodical *S.B.U.A.M.* He said that "architects and engineers don't know each other". Pierre Bourgeois identified the problem that one person (the architect) cannot harness the "entirety" of knowledge and power, and sees the solution in coordinated efforts, consultation by specialists and agreement of technicians (Bourgeois 1937).

This case study shows that the discussion on the roles of the architect and the engineer cannot be simplified into a formal or technical discussion. The collaboration on the Booktower more or less demonstrates this as technical (or technological) knowledge was as much a part of the design as was the formal and urbanistic interventions. This is certainly reflected by the professionals collaborating on the project as multiple actors, including Cloquet and Desmet, have the dual engineer-architect profile. Also, Magnel approached the structure concerned with the necessary architectural sensibilities but wanting to create an integrated design. Indeed, building practices that would become mandatory by the 1939 law on the protection of the profession of architect were already implemented in the building process for the Booktower.

7 CONCLUSION

Even before the final acceptance of the Booktower, Ghent University entrusted Van de Velde with the expansion of the Faculty of Literature and Philosophy, which was to be built right next to the Booktower complex. In 1947, a contract for the detailed design was signed both by Van de Velde and his assistant, architect Eugène Delatte, who eventually took over the project. In most literature, authors contribute the fact that Van de Velde often relied on assistants due to his advanced age but it also seems he embraced the culture of collaboration as a means to reach his goals.

It is becoming increasingly clear that Van de Velde took on a role of conceptual architect only concerned with the formal design of the project. He designed the form of practically all the elements in the project, from the volumetric shape and urbanistic planning to the details of table legs. It is clear that Henry van de Velde was firm on the tower typology from the early design phase onwards. In addition, archival material on the later phase's states that Cloquet did not take any formal design decision without the consent of Van de Velde. Cloquet worked in close collaboration with Van de Velde but the archival material shows that the latter was not concerned with the practical implementation of the design. The executive tasks of the project were passed on to Cloquet who prepared the "paperwork" for its execution. Importantly, Cloquet also closely collaborated with the administrative powers.

Although the lines of the Booktower clearly bear the mark of Van de Velde, such as the rounded corners that form a recurring theme in his later work, it is undeniable that Magnel also had a major impact on the design. However, his interventions remain hidden to most observers, as is the case for example with the columns within the tower, which were incorporated in the shelves but also the Vierendeel girders were literally concealed by interior skylight windows so that the impressive structure (necessary for such kinds of architectural intervention) was not visible from the large reading room. The contributions of both Cloquet and Magnel were not only "invisible" but also less valued, which was translated not only in terms of their honorary wages at the time itself but also in a lack of historical appreciation.

This paper suggests that the genesis of the library complex of the Ghent Booktower is deeply rooted in a culture of collaboration in building. Culture defined here as not only conditioned by a set of customs and values but also by the behaviour of people (Kroeber et al. 1963). Primary and secondary sources reveal that the professional team composed for the Booktower was involved in reoccurring collaborative efforts for three other buildings as well. This reveals an institutional practice. Jürgen Renn links the production of knowledge and institutions: "Institutions form the bases of knowledge systems, which then in turn become the condition for those institutions' stability and further development" (Renn 2020). This is also true for the processes that governed the construction of the Booktower as the institution drew on the knowledge of its professors which in their turn contributed to the realization of its patrimony. This institutionalization hints at two conclusions on the quality of this collaboration. First of all, the professionals were able to work together rather well as conflicts got resolved and did not halt further collaborations. Secondly, almost all the professionals were linked to the university, to a large extent the "real" commissioner of the projects. Each of the engineers and architects could contribute to the building projects with the most recent, state-of-the-art, knowledge and techniques in order to build exceptional and innovative buildings.

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Building the Estado Novo: Construction companies and public works in Portugal (1933–1974)

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ABSTRACT: The findings here result from the research done within the PTBUILDS19_20 project, which aims to set up a digital knowledge platform to map Portuguese construction history during the 19th and 20th centuries. An overview is presented on the public works produced by the 13 most important construction companies in Portugal during the Estado Novo period. Around 364 infrastructures are studied, with discussion of their typological distribution, location and chronological relation to individual actors (firm founders, engineers and architects), other collective actors (other companies, public institutions, materials producers and vendors), political events and economic cycles. The comparative study of building techniques and structural solutions used in each infrastructure typology is approached by identifying different technological periods for each infrastructure typology. The paper concludes that the study of construction companies is an important task since there is an important historiographical gap to be bridged in the study of the 20th century construction industry in Portugal.

1 INTRODUCTION

The aim of this paper is to discuss the results obtained from two virtual exhibitions dedicated to Portuguese construction companies active at the turn of the millennium within the framework of the open-access digital platform PTBUILDS19_20 (https://www.portugalbuilds.org). The analysis is focused on how 13 of the most influential companies in public works contributed to the history of construction in Portugal during the Estado Novo period, from 1933 to 1974.

The platform PTBUILDS19_20 uses as its main tool Omeka, a content management system widely known in digital humanities for publishing online exhibitions and collections based on digital units called items.

The first digital exhibition, entitled "Building Contractors in Portugal at the Turn of the Millennium", focused on building contractors and their construction works. Despite being central to the building sector, the endeavours of these actors have received little attention in historiography that opts in favour of other professional groups such as architects and engineers. The exhibition guides the user through the historical company profiles; biographies of the firm founder(s); timelines; detailed information on a selected number of works; and related information concerning individual and collective actors, materials, machines, written studies and legislation. The second exhibition, "Born in the 20th Century: Portuguese Construction Companies and their Works" complements the first exhibition, making it possible to find on the world map (OpenStreetMap base layer) the location of each company's construction works, classified into 25 different types of infrastructure: dams, bridges, roads, railways, airports, harbours, buildings (housing, religious, public administration, justice, defence, industry, hospitals, schools, laboratories, hotels, commerce, monuments, stadiums and sport compounds, theatres and cinemas), infrastructures for power or water supply, waste, telecommunications and landscaping works.

The two exhibitions cover 16 companies and the entire 20th century. Nevertheless, only 13 firms were considered representative of the construction sector for the period 1933–1974 based on their foundation date and the number of works they executed in that period. In this paper, the companies analysed are (by date of foundation): Soares da Costa (1918); Teixeira Duarte S.A. (1921), OPCA (1932), Amadeu Gaudêncio (1935), Mota & Companhia (1946), Construtora do Tâmega (1946), Somague (1947), Novopca (1947), Construções Técnicas (1950), Engil (1952), Alves Ribeiro (1955), Sopol (1959) and Edifer (1966).

Historical data were made available in different support types – images, videos, graphics, diagrams and maps – and proved to be fragmentary in nature. For all companies, it was possible to find online portfolios of construction works executed only in the last decade. Limited complementary information about their histories was found only in a few commercial publications. In this rarefied panorama, the only exception was OPCA, about which an important historical research was available (Soares 1992). In some cases, different

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governmental and municipal archives and other indirect sources such as specialized journals bring together a disparate amount of information.

The platform was structured into four major types of historical objects for analysis: 1) Individual Actors, 2) Collective Actors (institutions and associations), 3) Concrete Objects (building works, materials and machines), and 4) Abstract Objects (legislation, patents, scientific and technical publications). Several items, for example texts and images, were associated with each object using the Dublin Core metadata protocol. At the present time, approximately 1,560 items referring to the period 1918–2000 are already available for consultation. Of those, 1,130 are public construction works identified by a short description, execution time coverage and georeferencing. Around 92 individual actors (engineers, architects, entrepreneurs) and 36 collective actors are associated with a selected number (3 to 5 per firm) of construction works representative of each firm's development. The present analysis considered 470 items, of which there are 364 public works, 92 individual actors, and 14 collective actors.

Given Omeka adopts the logic of the exhibition practice of collections, such as those belonging to museums and cultural institutions, the historical objects on the platform result from an interpretation of the proposed curatorship (Crew & Bunch 1990; Tilden 1957). In turn, this interpretation can generate multiple meanings that users – as active learners – develop when using both digital tools and data. This means that both the objectives and possibilities of data interpretation can be reformulated to yield new research hypotheses. In this sense, this iterative process translates into a movement that begins with the data collected, continues with its introduction into the platform, and is completed by analysis using various tools (georeferencing, creation of relational tables). This all gives rise to more research, new data on the platform and, consequently, new results.

This study takes into consideration different possibilities of interpretation, in particular the potential for changes of scale (Struck et al. 2011) and different relationships between the actors in the construction field. Firstly, the companies in their historical, political and socio-economic contexts are examined before describing the transformations of the building processes they employed during the period under study. Then, there is comparative analysis of their activities from different perspectives: the typological, geographical and temporal distribution of the construction works. Last comes analysis of the relationships between the individual actors involved in each company and their influence on the merging and launching of companies.

2 PUBLIC WORKS BEYOND ENGINEERS AND ARCHITECTS

During the authoritarian regime covering the Salazarist (1932–1969) and Marcelist (1969–1974) regimes established by the 1933 Constitutional Charter and overthrown in the 25 April 1974 revolution, the study of public works in Portugal was approached from different points of view within the sphere of the history of architecture, engineering and urbanism: the study of emblematic buildings using reinforced concrete (RC) in its full plastic capacity (Tostões 2015), biographies of engineers and architects (Costa 2012), social housing policies (Agarez 2020), and infrastructures in Portugal and the former Portuguese colonies (Milheiro 2017) (Brites & Correia 2020). No systematic studies have yet been produced outside the traditional engineer/architect dichotomy or social politics field to include the study of building companies as fundamental actors in the sphere, examining the construction works they executed and their relationships with the transformation of techniques, machines and building materials.

To understand the action of public contractors during the Estado Novo, one must understand the political and economic context of the construction sector. As of the first government of that period led by Salazar from 1932, public works became a fundamental tool for the implementation of a new order based on territorial management and control. At the same time, the establishment of a "spiritual politics" rooted strongly in nationalism led to a first campaign to build infrastructures that would be ready in time for the 1940 World Exhibition in Lisbon, celebrating a double centenary (the country's independence in 1140 and the restoration of independence in 1640). The first campaign – which lasted until 1948 (the 15th anniversary of the Constitutional Charter) due to the slowdown caused by the Second World War (WWII) – consisted in the restoration of monuments and the construction of new primary and secondary schools, universities, social housing, priority bridges, airports in Lisbon, Porto and Santa Maria (the Azores), the national stadium, new prisons, a new Lisbon hospital, government buildings as well as the improvement of the main maritime ports. With the end of the WWII, Portugal became a NATO founding member and a Marshall Plan recipient. In this new context, a cycle of three national development plans followed: the first plan from 1953 to 1958; the second from 1959 to 1964; and the third from 1967 to 1973. In association with the national development plans, a campaign of inaugurations was put in place each year as a systematic propaganda strategy of the regime focused on the personality cult of Salazar. Those inaugurations always took place at the same time of year: from 27 April to 28 May. The first date celebrated the day when Salazar became a member of the government for the first time, while the 28th May marked the 1926 Revolution. Every year, public works inaugurations were listed in a catalogue organized according to district and infrastructure type.

The design and approval of the improvement projects financed by governmental schemes for large-scale expenditure were assured by the engineers and architects of governmental institutions and directorates of the Ministry of Public Works (MOP). Part of the projects was executed by private engineering and architecture firms based upon a public call for bids or by invitation. The works were normally adjudicated to the building company offering the lowest priced tender. Anachronistically, procurement procedures for public works contracts were ruled by a law dating from the monarchy (Decree 4 October 1897) with very few changes since. According to this regulation, almost every chartered builder could present a tender for any kind of public work. This situation began to change in 1950 and 1952 with the creation of the two new builder associations (AICCOPN in Oporto and AECOPS in Lisbon) that replaced the Northern and Southern guilds founded in 1890 and 1892. Since the beginning, almost all of the 13 contractors selected for this study were represented on the executive boards of the two associations. The lobbying of government by these new associations resulted in a new national code (Decree 40623, 1956) classifying contractors under 17 categories of different technical specialties: special foundation works, metallic structures, RC works, prestressed RC works, maritime works, airports, bridges, dams, etc. In each association, membership was thus decided based on the evaluation of the technical and material capacity to execute each of the categories of works. In 1967, lobbying by the two associations was also successful in bringing about the issue of new national codes: a new procurement code for public contracts with price review clauses (Decree 47.495, 1967) and regulation on construction in the private sector.

The enterprise of public contractors in Portugal was thus rather confined by a bureaucratised public procurement and corporatist control of their business. These political and economic constraints help explain the transformations occurring in the building processes used by the selected companies under the Estado Novo. In fact, consulting the list of construction works executed by the 13 companies, one can read a history of the evolution of reinforced concrete (RC) in the Portuguese construction culture. Under the "Regulamento de Betão Armado" – the national code published in 1935 that replaced the first code from 1918 – the different development plans applied concrete in a very pragmatic, economic and rational way, considering the availability of materials and the percentage of engineers recently trained in calculating RC structures. In reality, RC was only included in the curricula for engineers by Government Decree no. 2103 of 1915, which created the *Cimento Armado* program at the Faculty of Engineering of Oporto, held for the first time in 1919–1920 (Rodrigues 1920). In 1918, it was the turn of the Instituto Comerciale Industrial de Lisboa (Decree 5029, 1918) to establish a study course similar to that in Oporto.

Therefore, RC started to be used primarily in structurally complex infrastructures with important span lengths, special foundations, high load bearing and durability qualities, such as bridges, reservoirs, dams, hydraulic works, docks, airports runways, industrial plants, and important building structures including public markets, banks, hospitals, stadiums, ministries, prisons, cinemas and theatres. In housing, until the 1950s, reticulated RC structures were applied mainly to solve spaces with bigger spans and cantilever elements of facades in conjunction with traditional masonry walls. Relevant examples are the Massarelos refrigerated fish warehouse and auction building in Porto with a 10 m-high porticated structure and 20 m span beams executed by OPCA (1933–35); the new porticoed facade of the Assembly of the Republic founded on driven cast in-situ piles (Teixeira Duarte 1933–42), the Arroios-Lisbon market (Amadeu Gaudêncio 1938–42) or the massive new hospital in Lisbon-Santa Maria, a nine-storey building with 128,000 m^2 of floor area (Amadeu Gaudencio 1940–1952). In all of these building types, the wider opening of facades was commonly enclosed with metal windows of laminated glass. This new, cheaper and reliable industrial material was easily available as of 1941 thanks to the new COVINA glass plant, set up after the forced merger of the seven older plants that were producing glass using manual methods.

The limited use of RC was determined by a self-sufficient and state-protected domestic Portland cement market fed by seven main plants opened consecutively on mainland European Portuguese territory: Alhandra (1894), Outão (1906), Maceira-Lis (1923), Pataias (1949), Cabo Mondego (1950), Cisul-Loulé (1973) and Cinorte-Souselas (1974). On mainland Portugal, the yearly Portland cement production had always enjoyed steady growth, as evident in the following production figures: 70,000 tonnes (1931), 273,000 t (1941), 245,000 t (1942–1944), 573,000 t (1950), 600,000 t (1952) (Oliveira 1999: I-325). In 1959, the Alhandra plant's new 167.6 m-long rotary kiln with a yearly capacity of 500,000 t was considered the biggest kiln of that type in the world. In 1975–1976, Portugal's annual Portland cement production was approximately 3,850,000 t with average national consumption of 3,000,000 t (Oliveira 1999: I-462). However, contrary to the growing importance of the cement industry, Portugal was for a long time dependent on steel imports. The monopoly over imports held by just a few companies was only broken in 1961 with the creation of a national steel plant in Seixal with a capacity for 250,000 t/year of laminated products of which 150,000 t/year was rebar for the building sector (Pereira 2003, 1188). The increasing demand for the two RC primary products was mainly determined by the growth of the public construction sector, the private sector accounting only for a residual part of the consumption of Portland cement and rebar. Portland cement concrete was also used for the rigid airfield pavements at the new airports in Lisbon (Teixeira Duarte 1942) and Porto (OPCA 1942). The aircraft hangars of those two airports were covered with the first RC cylindrical shells. The Lisbon shells had a 42 m span and were 7 cm thick.

But it was only after WWII with the 1945 national road plan and the creation of development plans that public works attained more stable and continuous

Figure 1. Bemposta dam under construction (MOP 1963, 25).

Figure 2. Cellular concrete blocks under production in Porto Hospital (Revista Técnica no. 189, 1949).

growth. In this context, a series of priorities were added to those defined by the 1938–40 campaign, mainly in the fields of electrification and irrigation (dams, hydraulic works, hydro and thermoelectric plants). The RC technological improvements were much appreciated for all these facilities.

Massive volumes of concrete were used in the construction of the dams built in the main Portuguese river basins: Cávado, Ave, Douro, Vouga, Mondego, Tejo, Sado, Mira and in the Algarve. From the beginning, Somague executed several cylindrical arch dams: Alto Ceira (1949), Castelo de Bode (1951) and Odiáxere (1958). Double curvature arch dams followed: Cabril (Somague 1954), Bouçã (OPCA 1955), Picote (OPCA 1958) and Varosa (Somague 1972–76). And there were also concrete gravity dams: Bemposta (Somague 1964, Figure 1), Roxo (Construtora do Tâmega 1967), Carrapatelo (Sopol 1972) and Valeira (Somague 1972).

In the field of social housing construction, the prefabrication of concrete blocks, windows and door frames became extensively used for the first time in the Bairro de Alvalade development (OPCA 1947) and replicated all over the country in large constructions, such as the São João Hospital in Oporto, built in cellular concrete blocks in 1949 (Figure 2).

In the 1950s, industrial prefabrication of beam-and-block floor systems began with companies including Somapre, and other systems based on Stahlton beams applied in new shell roofs like that of the Bom Sucesso Market in Oporto (1952). In the 1960s, NOVOBRA was the most widespread approved beam-and-block floor system. Several RC shells were also built for large pavilions like the cast-in-place parabolic hangar (Figure 3) with a grid of arches (40 m span, 16 m rise, 98 m long) for the Fair held by the Industrial Association in Lisbon (Construções Técnicas 1952–55) or the 25 m diameter dome for the Lisbon Planetarium (Novopca 1964).

Figure 3. Pavilion for the Fair of the Industrial Association in Lisbon (MOP 1957).

With the 1956 Decree, public contractors started to specialize in the most demanding of the 17 technical categories mentioned above. In the bridges category, the most common solution in effect for average spans (20–40 m) up until the 1960s used continuous girder bridges with beams cast monolithically with the deck; for larger spans, many open-spandrel deck arch bridges were built. An example of the former solution is the Vale da Ursa bridge in Tomar (9 × 30 m spans, Somague 1949–51). An example of the latter is the bridge over the Sousa river, a ribbed, open-spandrel parabolic arch bridge with 115 m span and 14.8 m rise, built by Novopca in 1950–52 and advertised by the company as the longest RC arch bridge in Portugal at the time. After the first prestressed concrete bridge was constructed in 1954 (Vala Nova, Benavente, 3 simple beams with 36 m spans), the new construction method became commonly used in increasing span lengths. Soon after, a bowstring arch bridge with a prestressed deck (47 m span) was built in Sacavém (Construções Técnicas 1957). A few years later, SOPOL was able to build the 945-m long access viaduct to the metallic suspension bridge over the Tagus river in Lisbon (Figure 4), a cast-in situ post-tensioned prestressed concrete segmental box type bridge constructed by cantilevering (38.0 m maximum cantilever span) on top of double piers with a maximum height of 64.0 m (MOP 1966a).

Alongside this specialization, a firm's position as the exclusive domestic licensee of an international building system patent also helped to increase competition. This was the case of Construções Técnicas and Engil, for example. Each firm held the right to use a different slipform for cast-in-situ high-rise structural processes: Construções Técnicas with the Prometo slipform (AB Bygging) as of 1953 and Engil with Siemcrete (Siemens-Baunnion) as of 1969. In

Figure 4. The suspension bridge and access viaduct under construction. Far left: the Cristo Rei monument (MOP 1966b, 28).

consequence, in 1969 Construções Técnicas was able to announce the construction of the highest silo in Portugal (Beato-Lisbon, height 40 m); and, in 1970, the construction of the highest chimney (Siderurgia Nacional, 130 m). With the Siemcrete system, Engil executed the core of tall buildings and the piles of the Tourém Bridge (1970–72), with a cast-in situ deck supported by prefabricated pre-stressed concrete beams built by cantilevering.

3 COMPARATIVE ANALYSIS

Bearing in mind the political and economic context and the transformations in building processes during the Estado Novo, it is possible to proceed with comparative analysis of the activities of the 13 companies under consideration here based on the data gathered for the two virtual exhibitions.

As already mentioned, for the second exhibition, the construction works were divided into 25 different categories or typologies after combining the different material infrastructure classifications that would better summarize the 364 works under analysis (Torrisi 2009). Three main trends can be extrapolated from this from the typological point of view.

First of all, it is possible to find 11 companies that have executed works belonging to at least seven different construction typologies. OPCA and Engil did works classified in 16 and 12 typologies, respectively. Six of the companies report a balanced distribution of works by typology: Edifer, Soares da Costa, Teixeira Duarte, Alves Ribeiro, SOPOL and OPCA. Looking at Edifer and Teixeira Duarte, the number of works done under the most frequent typologies – "housing" and "water supply", respectively – do not exceed the percentage of works done in any other typology of the company portfolio by more than 22%. This confirms the marked versatility of a considerable number of these companies. As a second trend, there is a group of construction companies whose portfolio has a significant number of works focused on a limited number of typologies. This is the case of Amadeu Gaudêncio, Construtora do Tâmega, Construções Técnicas, Engil, Mota & Companhia and NOVOPCA. For Amadeu Gaudêncio, works under the "commerce" typology constitute approximately 36% of the entire portfolio. In the case of Construtora do Tâmega, "airport" represent about 40% of the works while in the case of Construções Técnicas 44% come under the category "industry". Mota & Companhia and NOVOPCA are two extreme cases: "airport" and "bridges" contain more than half of their portfolio – 64% and 53%, respectively. A third group of companies can be classified not only in a single typological category but in a group of related typologies. For example, the works done in the area of transportation (roads, railways, airports, bridges) by Mota & Companhia, NOVOPCA and Constructora do Tâmega correspond to 73%, 58%, and 55% of their total portfolios, respectively.

However, the activities of these construction companies can also be analysed from a geographical perspective. Concerning the location of works, they are concentrated in the districts of the two largest metropolitan areas – Lisbon and Porto – while approximately 50% of the total works are in mainland Portugal. If we add the Setubal district, part of the Lisbon metropolitan area, and Faro district, an urban and economic hub and tourist centre since the 1960s, these works represent 60% of the overall portfolio. Lisbon accounts for more than 25% of the portfolios of the vast majority of companies: NOVOPCA (36%), Engil (33%), Construções Técnicas (39%), Teixeira Duarte (50%), SOPOL (50%), Alves Ribeiro (74%), Edifer (88%) and Amadeu Gaudêncio 80%). In the Oporto metropolitan area, this asymmetry is particularly notable, with OPCA and Soares da Costa accounting for 31% and 73% of works completed in this area. These results demonstrate how the old phenomena of regional asymmetry and the "coastalization" of economic activities had an effect on the construction sector and, unsurprisingly, on the companies selected for this project. Outside of mainland Portugal, some singularities in the geographical activity of these companies emerges. For example, Construtora do Tâmega concentrated about 20% of its operations in Madeira and the Azores. In other cases, such as Mota & Companhia, the construction effort was mainly in Portuguese-speaking territories such as Angola. If we combine these results and focus on a single construction company, this reveals the most represented category of works in a specific location. Alves Ribeiro, for instance, accounts for a substantial proportion of works in the Lisbon area in the "airport", "road" and "sport" categories. Likewise, Amadeu Gaudêncio concentrates much of its business in Lisbon, in the "commerce" category; in contrast, the works classified under the "health" and "recreation" typologies are dispersed throughout the country. Novopca distinguishes itself in the "bridges" category for a significant number of districts. In turn, Construções Técnicas is characterized by both its intense activity in Lisbon and an even more proliferous undertakings in the now former Portuguese colonies, specifically in "ports" and "industry".

To conclude this comparative analysis, temporal analysis explains the response of these companies to

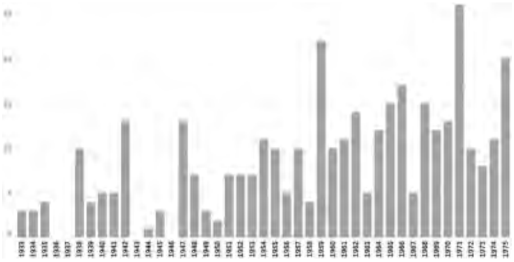

Figure 5. Yearly construction works by the 13 companies (PTBuilds19_20).

the different historical situations (Figure 5). In fact, three spikes corresponding to three key moments in the history of public works can be identified: 1938–1940, the WWII period and 1959–1966. The first period corresponds to the first campaign of the Estado Novo regime. Despite its position of neutrality, Portugal experienced a decline in the construction sector during WWII.

After the war, 1966 became the new milestone for the Estado Novo's, the year dedicated to celebrating the 40th anniversary of the 1926 revolution. For that reason, from 1959 until 1966 around 7,500 public works were inaugurated and listed in the Ministry of Public Works "Commemorative Plan". Some of the most emblematic works here include the Cristo Rei monument in Almada to thank God for saving Portugal from WWII (82 m high, RC porticated pedestal topped by a 28 m statue of Christ, OPCA); the suspension bridge over the Tagus river (the longest suspension bridge in Europe at the time); the Luanda Airport in Angola (Mota & Companhia) or the Sacavém viaduct on the A1 highway (RC driven piles, 1 m diameter, 50 m depth, Construções Técnicas). In summary, both 1938 and 1959 saw the emergence of two strong public works campaigns driving the growth of the vast majority of companies under analysis.

4 THE HUMAN ELEMENT

The study of the relationships among individual actors (such as builders, architects and engineers) and collective actors (such as companies or institutions) involving the 13 companies provided for a better organization of facts that, from the beginning of the study, seemed detached and fragmented. Firstly, different professional and personal relations within the building sector were identified. The Condicionamento Industrial, the regime's protectionist and interventionist policy, allowed for a limited group of actors operating in the public works sector given the narrow nature of the procurement selection process. Indeed, the vast majority of industrial incentives created by the government ended up boosting the growth of already well-established economic groups alongside the creation of a few new ones.

Numerous examples of family dynamics in the foundation and consolidation of these companies can be found, alongside the converging interests of professionals that had begun collaborating when working on projects together. Within the dynamics of the creation of companies, family-based setups are rather common. Most of the companies studied had a specific family name as its majority shareholder: Mota (Mota & Companhia); Fonseca (Construtora do Tâmega); Moniz da Maia (MSF); Alves Ribeiro and Teixeira Duarte at their homonymous companies; Vaz Guedes (Somague); and the Pires Coelho family for Edifer.

However, to fully understand the role of family ties in the evolution of these companies, one must study the relationships between actors within and between the firms (Figure 6). In this respect, we must start with the Teixeira Duarte, Moniz da Maia and Vaz Guedes families. Ricardo Esquível Teixeira Duarte and Bernardo Ernesto Moniz da Maia, both civil engineers and well-known businessmen, were also cousins. Ricardo was the son of Maria da Conceição Esquível Moniz da Maia, and Bernardo was the son of her brother, Ernesto da Cunha Moniz da Maia. The two cousins and José Vaz Guedes jointly founded a construction company called Sociedade de Empreitadas Moniz da Maia, Duarte & Vaz Guedes. José Vaz Guedes had already built the first Portuguese concrete highway pavement between Lisbon and the National Stadium (1944) with Bernardo. However, disputes regarding the order of the names in the company's brand put an end to this project and led the cousins down different paths. Ricardo founded the Teixeira Duarte company in 1921 and Bernardo created the Moniz da Maia & Vaz Guedes (later called Somague) with his long-time friend and colleague José Vaz Guedes in 1947. The Castelo de Bode Dam works were immediately commissioned to the recently founded company that same year.

Another case of intricate family relations concerns the Mota and Fonseca families and the two companies that would later become major economic groups. The relationship started with the marriage of Manuel António da Mota and Maria Amália Guedes Queiroz de Vasconcelos in 1946. From that moment on, the Mota and Fonseca families engaged in a strategic alliance that would associate Manuel and Joaquim da Fonseca, his brother-in-law, in the creation of Construtora do Tâmega one year later. The new company would operate in mainland Portugal, while Mota & Companhia focused on Angola. Again, eventually the two families would go their separate ways: in the 1960s, the Mota family stayed in control of Mota & Companhia (today part of Mota Engil) and the Fonseca family took full control of Construtora do Tâmega.

Although family associations are observed mainly in the founding or initial years of each company, these connections extended to actors belonging to different professions or to both public and private sectors. In the first case, OPCA is the most evident example. This company, founded in 1932, soon undertook works of great importance, especially in the city of Oporto. The

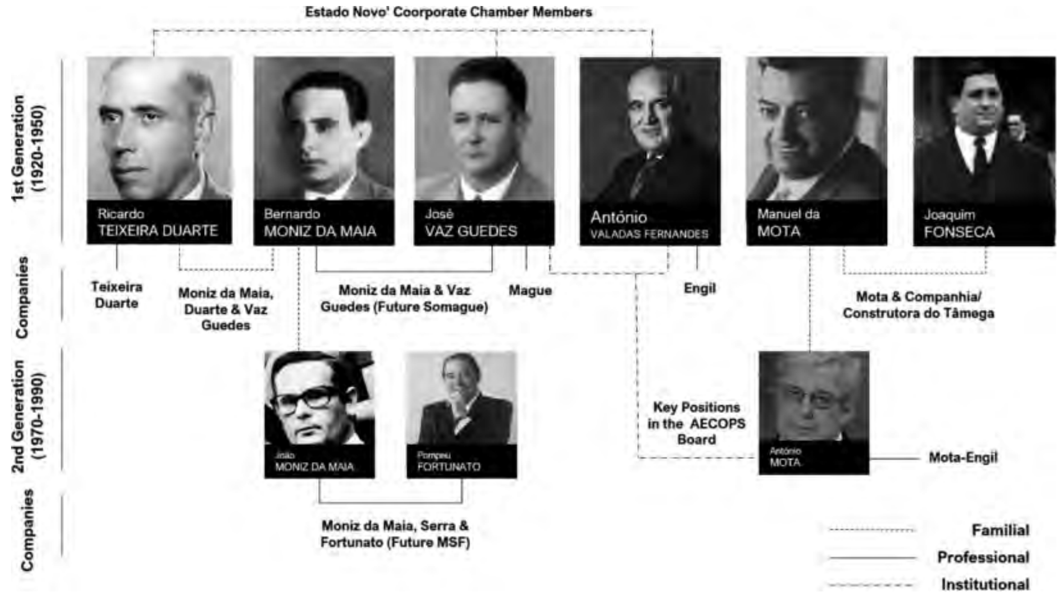

Figure 6. Family, professional and institutional relationships among company founders (PTBuilds19_20).

joint venture between the two brothers Manuel (civil engineer) and Januário Godinho, who would become a much respected architect, contributed strongly to the business image of the company, with innovative RC buildings like the Lusitania Commercial Factory plant (1932), the Sentieiro Garage (1932) and Massarelos cold storage and fish auction (1933). For the second typology of relationships, the names of Ricardo Teixeira Duarte and José Vaz Guedes and António Valadas Fernandes (Engil founder), are noteworthy. The three men were simultaneously company owners and members of the Corporative Chamber of the Estado Novo in different legislatures, guaranteeing their presence at once in private and public sectors. At the end of the 1960s, the second generation of the Moniz da Maia family (who no longer owned Somague), would once again be involved in the foundation of a new company. This time, João Moniz da Maia (Bernardo Moniz da Maia's son) joined the Fortunato family to create Moniz da Maia, Serra & Fortunato, today known as MSF.

Despite the importance of family and professional ties, other types of relationships should be taken in consideration: the relations among construction companies. These types of connections are particularly interesting in founding moments. Amadeu Gaudêncio was one of SOPOL's founders in 1959, while OPCA was one of the founding shareholders of Novopca in 1947, a company that operated until the 25 April Revolution as a branch of OPCA.

Beyond the spectrum of companies analysed in this paper, there is also Indubel, with majority shareholders at the time of its founding in the 1960s being MSF, and the metalworking company Mague, founded by Somague in 1952. The peak of these tight entrepreneurial networks would be reached only decades after the end of Estado Novo, at the end of the millennium, when several acquisitions and mergers between the major companies took place. For example, the merger of Engil and Mota & Companhia led to the creation of one the largest public works conglomerates in Europe.

These provisional results back up the idea that the Estado Novo was, for the construction company sector, a period with "a high degree of concentration", especially in relation to industrial and financial groups.

5 CONCLUSIONS

In 1974, the year of the revolution that ended the Estado Novo regime, many new public and civil contractors were members of both the North and South Builders Associations. Prestressed concrete was a common solution for many types of structures; prefabrication was present in all building processes; impressive foundations methods were applied; metallic structures like the Boeing 747 hangar in Lisbon and record-breaking dams such as the Cabora Bassa in the Zambezi River were under construction. The 25 April Revolution and European Union integration would profoundly change the volume, the procurement process, the geography and the actors involved in public works in Portugal. This paper reflects only the initial results focused on the Estado Novo period based on the interpretation of two virtual exhibitions aimed to give a panoptic view of Construction History in Portugal. For an exhaustive study of the problematics of contractor activities, other companies – active during that period, also responsible for emblematic construction works and with major undertakings – must be studied to refine the precision of these results.

There still remains plenty of scope to continue unpicking the entangled history of the building sector and the relevance of the construction companies, actors hitherto so little taken into account of in Portuguese construction history.

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History of Construction Cultures – Mascarenhas-Mateus & Paula Pires (eds)

The introduction of prestressed concrete in Portugal: Teixeira Rêgo

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ABSTRACT: This paper addresses the professional career of António Teixeira Rêgo, Portuguese engineer, born in 1906, died in 1967. Professor at the Faculty of Engineering, he combined teaching and research activities with intense professional practice, working with the most important northern architects and being connected to some of the most notable works of the city of Porto, such as the Passos Manuel garage, the Coliseu do Porto, or the Casa de Serralves. He was responsible for the introduction of prestressed and light prefabrication technology in Portugal, discussing his experiences in international forums.

1 INTRODUCTION

The history of architecture, and the history of the construction of the city of Porto, in the 20th century, have been the target of an increasing number of studies in recent years, the result of greater academic research. The studies are generally focused on the work and professional careers of architects, analysis of the transformation of areas of the city, or certain types of buildings. An important gap identified is the lack of an equivalent investment in research that focuses on the professional career of civil engineers, the processes of introducing structural calculations into the licensing permits, their role in the implementation or dissemination of new materials and constructive systems, and their impact on the industrialization of construction processes. We can point to research on the teaching of engineering (Matos & Sampaio 2019), the careers of some engineers (Sampaio 2019), on calculations and regulations (Póvoas & Vale 2018), and on the history of engineering (AA.VV. 2002; Viseu, 1993), among others.

One of the least studied engineers who developed a fruitful professional life between the 30s and 60s, participating in significant projects of the city of Porto such as Garagem Passos Manuel, Coliseu do Porto, or Casa de Serralves, is António Augusto Guimarães Teixeira Rêgo, professor at the Faculty of Engineering. Along with theoretical and scientific production parallel to his activity as a designer, he would participate in international circles of technical knowledge transfer, namely in congresses and conferences, and would be responsible for the introduction of prestressed technology in Portugal. As Viseu (1993, 151) states, in Portugal Teixeira Rêgo "was for prestressed concrete as (…) the engineer Moreira de Sá was for reinforced concrete (Hennebique system)". His professional practice followed a period of change in construction systems, and consolidation of the use of reinforced concrete in Portugal, being active at the start of the industrialization process and prefabrication of construction in the 50s. Research has revealed his importance in the construction panorama and in the introduction and systematic use of new materials such as reinforced and prestressed concrete. This article is the first presentation of ongoing research.

2 ANTÓNIO TEIXEIRA RÊGO, ENGINEER AND PROFESSOR

António Augusto Guimarães Teixeira Rêgo, born in Matosinhos in May 1906 (d. Oct. 1967), graduated in civil engineering at the University of Porto where he finished his course in 1935, with his final internships at the Port of Leixões (5 July 1932); Anglo Doutels Engineering and Harbor Works, in Leixões (14 November 1934) and finally the Water and Sanitation Service of the Porto City Hall (17 January 1935) (FEUP. Arquivo, 1932–5). During his student days, between 1932 and 33, he was the editor delegate of Porto for the magazine *Academia Portuguesa* (S:N. 1933, 2).

In 1936 he began his career as a teacher. By order of the Rectory on 29 May 1936 he was appointed

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for three years to the position of assistant of the 3rd Group (Hydraulics) of the Faculty of Engineering, beginning on 14 June (Universidade do Porto 1926–1988, 1). He was finally permanently employed in August 1942. From 1940, he assumed responsibility for the subject "Industrial Hygiene", which the following year was renamed "Industrial Hygiene and Safety of Workers", and in 1942 he took over the subject "General Hydraulics – Hydraulic Machinery". In 1956, he ceased as head of "Industrial Hygiene and Safety of Workers", to become head of "Aerodynamics", a position that would continue until his death in 1967 (Universidade do Porto, 1926–1988).

In 1944 he presented his PhD thesis entitled "*Da Hidráulica: uma Ciência Experimental e Teórica* [Hydraulics: An Experimental and Theoretical Science]" (Rêgo 1944) which allowed him to be appointed to the position of 1st Assistant in March 1945, since he had already become an Assistant in 1936 (Universidade do Porto, 1926–1988). In his PhD, he defended the use of physical theories as necessary to knowledge acquisition of hydro-dynamics, the use of experimental data, which should be based on laboratory work using scale models, to confirm abstract knowledge. Most significantly, he defended the application of the principles of similarity that allowed models to be used to analyze hydraulic behavior (Rêgo 1944). It should be mentioned that in 1939 he advocated the "theory of similarity" in an article published in the *Journal of the Faculty of Engineering* (Rêgo 1939).

In 1942 he participated, in Porto, in the 4th Congress of the Portuguese Association for the Progress of Sciences, publishing the article "*Um método prático para a construção de tetos de grandes salas de espectáculos* [A practical method for the construction of ceilings for large concert halls]" using his experience in the works of the Coliseu do Porto (Rêgo 1942).

Between 1944 and 1952 he held "the position of member of the Higher Council of Public Works, (which he) exercised with the greatest competence and zeal the functions he was charged with" and was appointed again in August 1952 (Universidade do Porto 1953; Universidade do Porto 1926–1988).

His studies in Hydraulics, and his internship in Leixões Port, led him to an interest in the work of Eugene Freyssinet (1879–1962) the pioneer of prestressed concrete in 1931; an interest that would define his contribution to the national construction industry. From the end of World War Two, we find the application of this process in hydraulic works, such as the construction of the Rivières sur le Tarn dam which started in 1946, and the Orleans water tanks, also from 1946. The application of Freyssinet's methods using prestressed concrete were used in diverse works, most noticeable in the construction of bridges. This interest led Rêgo to participate in the very first congresses dedicated to the use of prestressed concrete. Thus, in June 1949 he participated in the *Journées Internationales de Pré-Contrainte* in Paris and Rouen where he presented (in Rouen) a paper on "*Processos portugueses de pavimentos de Betão Pré-esforçado* [Portuguese processes of prestressed concrete floors]". This meeting gathered 450 representatives from 18 different countries, where important oral contributions were presented, including by "M.M. Caquot, Freyssinet, Lossier, Colonnetti [and] Lévy" (BTSR 1949, 221; Universidade do Porto 1950).

In the 1950s, Rêgo participated in several international conferences where European cases of the use of the new concrete process were presented. In 1950, with a scholarship from the Instituto de Alta Cultura, he participated in the *Jounées Internationale de l'Association Scientifique de la Precontrainte*, held in Paris, Rouen and Le Havre, presenting a paper entitled "*Fenómenos da temperatura nas grandes mesas de fabrico de betão pré-esforçado* [Phenomena of temperature in large manufacturing tables of prestressed concrete]", later published in the French magazine *Travaux* in 1951 (Rêgo 1951b). In the same year, he participated in Ghent (Belgium) in the *Congrès du Beton Précontraint* presenting the paper "*Les activités portugaises dans le domaine de la précontrainte* [The Portuguese activities in the field of prestressing]" and another entitled "*Quelques remarques à propos de la fabrication de poutrelles en béton précontraint sur des tables vibrantes* [Some remarks about the manufacture of prestressed concrete beams on vibrating tables]" (Rêgo 1951b). Between 12 and 17 May 1952 he took part, in Madrid, in the first general meeting of the *Instituto Técnico de la Construcción y del Cemento*, which was organized as a higher course in concrete. He presented a paper entitled "*El empleo de los procedimientos Freyssinet en Portugal* [The use of Freyssinet procedures in Portugal]" (CSIC 1953), which was published, in 1953, in the magazine of the same institute (Rêgo [1953], 1953).

On 29 August 1952, in Cambridge, he participated in the inaugural meeting of the International Federation of Prestressed Concrete (*Fédération internationale de la précontraint* – FIP), and was appointed delegate by Portugal (Rêgo 1953). At the first FIP congress, in London in 1953, he presented the papers "*Pavimentos mistos de betão pré-esforçado* [Mixed floors of prestressed concrete]" and "*Cálculo do betão pré-esforçado baseado no critério da rutura* [Calculation of prestressed concrete based on the rupture criteria]" (Rêgo 1953). He also participated in the second congress, in 1955. In 1956, he published the article "*50 anos de betão armado em Portugal* [50 years of reinforced concrete in Portugal)" in the magazine *Concrete and Constructional Engineering* (Universidade do Porto 1959) and in 1958, in the FEUP magazine, the article "*Impressões de uma viagem a Angola* [Impressions of a trip to Angola]", with the report of his experience in the construction of a prestressed concrete bridge over the Mucoso River, a tributary of the Quanza River, 220 km from Luanda (Universidade do Porto 1960).

Teixeira Rêgo would make exploratory visits, combined with the congresses he participated in, privately or with students. Consolidating his knowledge, he made, in 1950, a private visit to the *Escuela de*

Caminos Laboratories, in Madrid (Rêgo 1951b). Later, in 1954, he accompanied the final year students on a study trip to France and Spain (Universidade do Porto 1955). In the following years he would host several conferences in Portugal dedicated to prestressed concrete.

This intense international activity of Teixeira Rêgo, and other colleagues, engineers and professors, was the result of the growing importance of engineering training and the engineer profession. In the 1930s two social groups were affirmed: "engineers and industrialists, who will give guidance to the economic development of the country, convinced that their ideas and qualifications will play a determining role in the conduct of economic policy" (Rollo 2002, 11).

The engineers' protagonism was also due to the implementation of reforms in technical education. In 1911, with the introduction of the Republican regime, a re-organization of the main Engineering schools was undertaken. Moreover, in 1915 and 1926, the reforms allowed: the renewal of study plans, the definition of an engineering graduate, and the introduction of theoretical-practical training including laboratory experiments, particularly in the testing of materials, with a strong emphasis on specialist knowledge (Matos & Sampaio 2018). It was within this framework of the acquisition of technical skills and competences that a generation of engineers developed, such as Antão Almeida Garrett (1897–1978), José Júlio de Brito (1896–1965), engineer in 1924 and architect in 1926, Francisco Jacinto Sarmento Correia de Araújo (1909–81), and also António Teixeira Rêgo (1906–67), our case study.

3 ANTÓNIO TEIXEIRA RÊGO, DESIGNER AND INDUSTRIAL PROMOTER

António Teixeira Rêgo began work as a structural designer soon after finishing his course in 1935, signing the Terms of Responsibility in several areas (reinforced concrete calculations and safety of workers) and working with different architects, such as Mário de Abreu, Cassiano Branco, David Moreira da Silva, Homero Ferreira Dias, Rogério de Azevedo and J.A. Brito e Cunha. He also collaborated with fellow engineers, for example, the team that undertook construction of the City Hall building and the project of the Massarelos berth (Rodrigues 1937, 184). We also find reference, in 1938, to his role as technical manager of the construction company Ferreira dos Santos, a large company in Porto, responsible for the construction of housing blocks.

His activity was intense. A total of 338 processes licensed between 1935 and 1952 (276 between 1935 and 1939) have been inventoried so far in the Historical Archives of the Municipality of Porto. About 150 correspond to the construction of new buildings and the rest to other types of works including the construction of garages and warehouses or small alterations, namely the construction of reinforced concrete slabs in kitchens and bathrooms of existing buildings. Terms of Responsibility in the neighboring Municipalities of Vila Nova de Gaia, Matosinhos and Vila do Conde were also identified, and a reference to a building in Lisbon. Further research may show a widening of his geographical area of influence.

António Teixeira Rêgo's period of professional activity corresponds to a time of great change in construction systems and in the construction industry in Portugal, mainly in what concerns horizontal structural elements, with a progressive replacement of wooden floors by several types of reinforced concrete slabs.

He was directly connected, as a designer, to a number of notable works in the city of Porto, such as the Garagem de Passos Manuel (1937–9), the house of Serralves (1925–43), the Coliseu do Porto (1939–44), the building block of the Palácio do Comércio (1940–54) as well as in nearby municipalities, such as the Matosinhos Cotton Warehouse (1950–1), the facilities of the Portuguese Cellulose Company in Cacia, Aveiro (1952–3), and the pavilions of the Seca do Bacalhau in Lavadores, Vila Nova de Gaia (1958–9).

4 INNOVATION AND NEW MATERIALS: THE COTTON WAREHOUSE AND THE INTRODUCTION OF PRESTRESSED CONCRETE IN PORTUGAL

Technical progress develops through the introduction of innovations. According to Schumpeter (1883–1950) innovation can consist of the production of a new product, the introduction of a new production process, the adoption of new management processes and business organization (Amaral et al. 2016). The motivations to introduce an innovation can be to obtain a profit, obtain an advantage over other competitors, gain competitiveness, but can also constitute an improvement in the quality of products and processes through compliance with international standards.

The introduction of prestressed concrete in Portugal, and its production methods, corresponds to the application of innovative techniques that had been introduced between the wars, resulting from the cumulative work of several engineers from 1886.

For E. Freyssinet it was introducing the use of prestressed concrete for consolidating the maritime station of Le Havre; being the first application of prestressed concrete in a large engineering work (Freyssinet 1951, 1). After Le Havre, other works became significant, namely the Balma Ship Model Basin in Toulouse, a major work created in 1906 at the instigation of engineer Louis-Émile Bertin (1840–1924), and with additions over the years, especially the opening in 1952 of a 1200 m long tank (Figure 1).

António Teixeira Rêgo, through his international contacts, became aware of the advantages of the new process and the value of better organization of the execution procedures it involved. He followed Freyssinet's technique as well as the work of engineer Yves Guyon, responsible for several works carried out by STUP

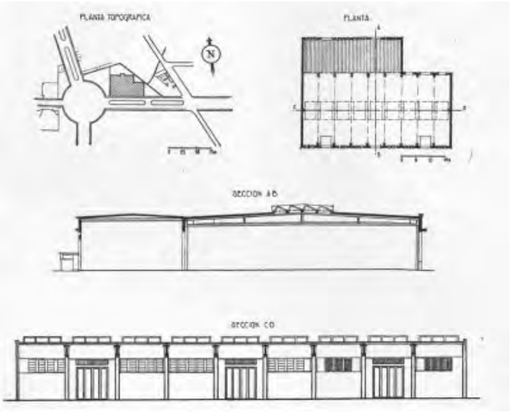

Figure 1. The Design of Cotton warehouse (Rêgo [1953]).

(*Société Technique pour l'Utilisation de la Précontrainte*), with innovative solutions that widened the use of prestressed concrete. Along with Myle J. Holley Jr – a professor at the Massachusetts Institute of Technology (MIT) – António Teixeira Rêgo promoted that prestressed concrete allowed for great savings in steel, a fact that made it immediately advantageous from an economic point of view (Rêgo [1953], 4).

He manufactured and employed for the first time in Portugal "prestressed concrete hollow slabs (Porto – August 1948), using a type designed in France, which was soon put aside. It was a beam of rectangular section, in a coffin, lightened with two cylindrical holes" (Rêgo 1958, 50).

In 1951, António Teixeira Rêgo published, in the magazine of the Order of Engineers, an article entitled "*A primeira construção portuguesa de betão pré-esforçado com cabos* [The first Portuguese prestressed concrete construction with cables]" (Rêgo 1951a) and in 1953 he published in the magazine of the *Instituto Técnico de la Construcción y del Cemento* another article about the "*Empleo de los procedimentos de Freyssinet en Portugal* [Use of Freyssinet's procedures in Portugal]" (Rêgo [1953]), following a conference in May 1952. In both, he describes in detail the plan for the construction of the cotton warehouse at, then, Av. Menéres, in Matosinhos, belonging to the firm Carlos Marques Pinto & Sob. Limitada, designed by the architect Homero Ferreira Dias (1904–60). The team responsible for the execution of this project and construction work was composed entirely of local technicians. Looking at the accounts of the prestressed structure the names of the following engineers stand out: Gustavo Natividade and Aurélio Morujão, from the technical office "Precomate" of Porto, under the guidance of António Teixeira Rêgo, who appears as coordinator of the prestressed concrete works (Rêgo 1951a, 19). The contractors were the *Cooperativa dos Pedreiros Portuenses* and Angelo Ramalheira (1908–75), a former student of Gustave Magnel, whose construction company would be linked with important national works, such as the School Hospital and the Crystal Palace sports pavilion in Porto, the headquarters of the *Diário de Notícias* and the block of *Águas Livres* in Lisbon. The granulometry studies of the concrete, formwork and execution project were carried out by engineer António Gonçalves, in collaboration with Ramalheira, who "had been in Paris between 1949 and 1950 where he had studied the system of fungiform slabs and prestressing" (Gonçalves et al. 2004) (Figure 2).

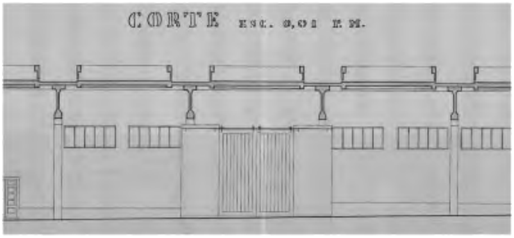

Figure 2. Close up of the architectural section of the Cotton Warehouse, with the representation of the structure (Matosinhos et al. 1950).

The warehouse, with its large span and considerable height, is still recognizable despite the transformations undergone over almost 70 years. It currently accommodates a large commercial area, and above the false ceilings can still be seen the beams and prestressed slabs of the initial industrial warehouse which was intended "for the storage of large imported shipments of cotton bales, after their unloading at the port of Leixões" (Matosinhos et al. 1950). Its construction was to follow the rules imposed by Ministerial Order that required these spaces to have waterproof and load-resistant flooring, fireproof insulated ceilings, and walls resistant to temperature variations, as well as meet the requirements of the fire-fighting services. It was thus decided to build a warehouse with a cavity wall of stone and concrete blocks, a terrace roof, windows with double frames, those of the south and west elevations being protected with brise-soleils executed in vibrated concrete plates, and those of the annexes at the rear executed in "gracifer", a reinforced concrete frame system (Figure 3).

The roof structure would be re-enforced with "large prestressed concrete master beams, calculated and executed using 'Freyssinet' (…) processes, a 7 m space between axes and with a total span of 32 m (…) the terrace (…) will be formed with prestressed concrete beams (Precomate), [with] a coating layer in cellular cement, of 0.05 m thickness, for thermal insulation" (Matosinhos et al. 1950).

According to António Teixeira Rêgo, the warehouse construction took advantage of the prestressed concrete characteristics, using master beams with a span of 32.40 meters, and "136 cables of 12 wires of 5 mm each, using Freyssinet cones and the work of jacks" (Rêgo 1951a, 5). These are "isostatic beams, calculated for a bending moment of 484,000 m.kg., with a 1.80 m. corner at the midpoint of the span and 1.10 on the supports. The maximum width (…) is 0.76 m

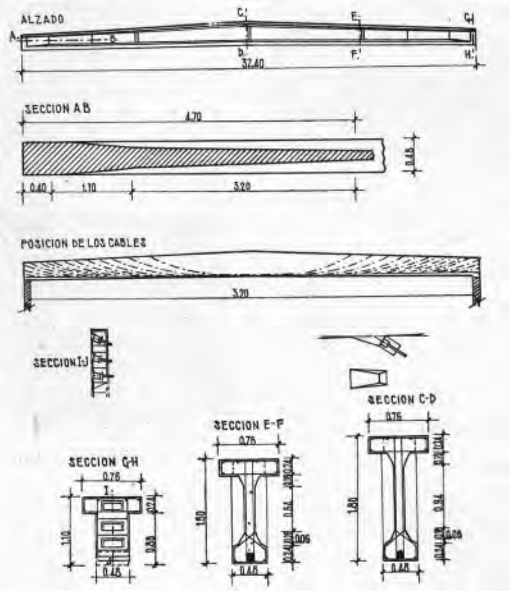

Figure 3. The design of the prestressed beams of Cotton warehouse (Rêgo [1953]).

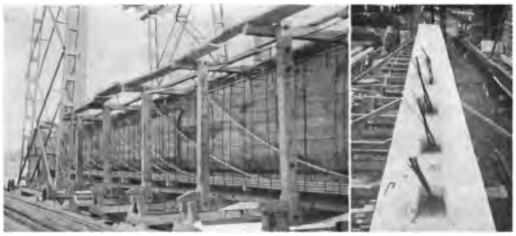

Figure 4. The layout of the prestressing cables, on the left, the anchorage of the cables, on the right (Rêgo [1953]).

at the flange and the minimum is 0.13 m at the web. Only one wooden formwork with a supplementary base plate was built on the ground" (Rêgo [1953], 7). The proposed system allowed faster manufacture by removing the sides of the formwork after 24 hours, keeping the base for six or seven days, and concreting a new beam with the laterals and the supplementary base (Figure 4).

The construction followed the requirements to obtain a concrete with the necessary granulometry, respecting the relation of water-cement, workability, form of kneading and application, and was achieved "as average values, resistances, at 6 days, usually over 300 kg/cm2, which are considered sufficient to proceed with the stretching of cables" (Rêgo 1951a). Rêgo also made mention of the use of six electric vibrators of national manufacture with 1.5 CV in the process of filling the molds that shortened the process of concreting the beams, which took on average four and a half hours to 16m3 of concrete (Rêgo 1951a, 7).

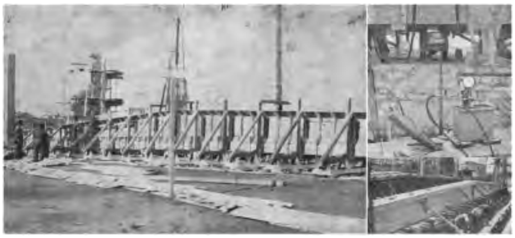

Figure 5. The beam formwork, on the left, and the electric vibrators used, on the right (Rêgo [1953]).

The beams were lifted on the seventh day "with the help of two metal towers of 20 tons each" (Rêgo 1951a, 11).

The slabs were made using prestressing, by means of "industrially manufacturing tubular beams, with adherent wires" with the space between them "filled with special type bricks, covered with concrete" (Rêgo 1951a, 12).

At the end of his description, António Teixeira Rêgo mentions that this warehouse in Matosinhos "was the first construction using prestressed concrete with the use of cables, without the use of foreign technicians, carried out in Portugal following the Freyssinet methods" (Rêgo 1951a, 19). He also stressed that its technical and economic viability was possible due to the cooperation between the designers and the technical office of the company *Precomate, Sociedade de Preconstrução de Materiais Lda.*, based in Águas Santa, Maia. It was one of the first European companies dedicated to the manufacture of prestressed hollow slabs of STUP patent (Sarmento 2005, 10), submitted to the evaluation of the National Laboratory of Civil Engineering (LNEC), becoming one of the first national industries to invest in prefabrication in the construction sector. It should be noted that after the publication of the General Regulations for Urban Buildings (RGEU) in 1951, all new constructive solutions would have a type-approval document issued by LNEC. This company, which was technically directed by António Teixeira Rêgo, and administered by other partners, is recognized as one of the first in Europe to successfully advance the industrial manufacture of prestressed beams (Lalande 1949). The investment made in Precomate, created by engineers, shows that the industrialization of these processes took substantial steps in the 1950s, after the issue of law n°. 2005 (14 March 1945) that promoted the "*Bases a que deve obedecer o fomento e a reorganização industrial* [Conditions with which the development and industrial reorganization must comply]". This was followed by the launch of the "*Planos de Fomento* [Development plans]" (1953–74), the first to cover the period from 1953 to 1958 and to be an instrument to stimulate the national economy in the post-war period, seeking to define an investment strategy more in line with the development prospects of the time (Figure 5).

António Teixeira Rêgo would lead in the manufacture of prestressed beams for the construction of the buildings of the Portuguese Pulp Company in Cacia, Municipality of Aveiro, also under execution by Angelo Ramalheira. For this project, 24.5-meter-long beams were built for the machinery room and 15.90-meter-long beams for the warehouse, being 4.92 in cantilever, which is the reason why he stated that "in addition to the parabolic cables characteristic of the system employed, these beams carry, in the support submitted to negative moments, an additional reinforcement, used for the first time in Portugal" (Rêgo [1953], 13). The suggestion to use the prestressed system, which "solved the problem of fast execution", was the result of an alteration proposed to the initial project made by the contractor, replacing the reinforced concrete porticos with an equal number of prestressed beams. The change to the initial solution "was studied in the technical office of engineer Ramalheira by engineer António Gonçalves, and was approved and adopted because it is the most advantageous and fastest" namely to allow prefabrication of the roofing of the main naves of the company independently of other works, leaving the interior space free (Rêgo [1953], 13).

Other works with prestressed beams were, in this decade of 1950, planned to be undertaken in the short term in the city of Porto, among them the new Lapa telephone center and the construction of a warehouse to repair the STCP buses, among others.

This engineer, professor and industrialist, argued that the prestressed concrete construction would allow the transition between craft production on site and industrialization of the process, supported by the new construction model and pre-manufactured elements. Support for this idea is evident in Rêgo's article "*Industrialização de pavimentos em construção civil* [Industrialization of floors in civil construction]" where he pointed out how the great alternative in civil construction is the prestressed concrete joist because "it was the prestressed concrete that completely solved the problem of designing the most convenient types of prefabricated floors of industrial provenance (…) allowing also to obtain more resistant joists and reduce the height of floors" (Rêgo 1958). However, one of the obstacles to the industrialization of these prestress construction systems was the large investment necessary for the construction of industrial facilities, requiring large installations, "projects that can only be made possible by powerful industrial companies" (Rêgo 1958, 49). But António Teixeira Rêgo's voice in favor of prefabrication in civil construction was joined by that of Antão Almeida Garrett who, in the same year of 1958, published an article entitled "*A habitação prefabricada* [The prefabricated dwelling]" in the magazine of the Faculty of Engineering of Porto in which he emphasized the importance of industrializing construction in order to advance with a "comfortable, well-built dwelling, in sufficient quantity to provide and maintain a voluminous production" (Garrett 1958, 25). Both professors of the Faculty of Engineering pointed to the need to replace craft methods with prefabrication, because only this would allow control of the measurement of the pieces, the greater operationalization of the work and a rationalization of construction. To the engineers' voices we can add that of architects, like Arménio Losa, who at the first national congress of architecture in 1948, presented two papers with the same focus, "Industry and Construction" and "Architecture and the new factories" (Losa 1948a; Losa 1948b).

António Teixeira Rêgo died on 7 October 1967, a year before his death having founded, together with Júlio Ferry Borges, Aurélio Morujão, and Joaquim Sarmento, among others, the Portuguese Prestressing Group (still active), formed the Portuguese group of the *Fédération Internationale de la précontrainte*, being the main partner and belonging to the associate bodies (Pipa 2016, 5).

5 CONCLUSIONS

António Teixeira Rêgo is a protagonist in the history of construction of the twentieth century, and pioneer of prestressed concrete in Portugal. A student of civil engineering at the Faculty of Engineering of the University of Porto, he was of the first generations of graduates who received a theoretical and practical training, based on experimentation with processes and materials. Professor of Hydraulics since 1936, he came to develop his career as an engineer of structural calculations in reinforced concrete, participating in numerous projects. Based on archival documentation, since 1949, he liaised directly with the engineers who introduced prestressed concrete into Europe, a connection which allowed him to safely assume the use of prestressed concrete in large span beams in the construction of the cotton warehouse in Matosinhos. Surrounded by a group of engineers, he advanced the prefabrication of prestressed beams, with Freyssinet's patent, and was technical director of one of the first European companies dedicated to this constructive system – Precomate, Sociedade de Preconstrução de Materiais Lda (Figure 6).

Aware of the challenge of industrializing these processes, António Teixeira Rêgo shared through professional magazines, at the congresses in which he participated, and in seminars, the methods of E. Freyssinet, obtaining orders from large companies to optimize an investment that required large capital and large spaces for production. The importance of the relationship with Angelo Ramalheira must be mentioned – they even had an office in the same building, at Praça Filipa de Lencastre in Porto – and is a subject that requires further investigation.

The introduction of prestressed concrete created new construction practices and processes that, combined with horizontal property regulation, allowed the introduction of new building models responding to new cycles of city development and of civil construction industrialization. The development of this new process was the result of the study and testing by

Figure 6. The Cotton warehouse in construction, with the prestored beams and the hollow slabs (Rêgo 1951a).

generations of engineers who had solid technical skills but also the ability to experiment and innovate in the context of design and execution of work.

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History of Construction Cultures – Mascarenhas-Mateus & Paula Pires (eds)

Claudio Marcello and his dam

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ABSTRACT: The paper explains the role of Claudio Marcello (1901–69) in the history of Italian structural engineering, and in particular his contribution to the language of "Italian Style" dams. Marcello designed about 40 dams, in the Alps, Sicily, Sardinia and abroad, in less than 30 years as technical director of Edison (1937–63), working in the extraordinary period of post-World War II and Italy's economic boom. The unique character of its design is internationally recognised right from the start. In Marcello's works, the very characteristics of 20th-century Italian engineering are readable, as investigated during the Research Project SIXXI–XX Century Structural Engineering: the Italian Contribution, ERC Advanced Grant 2012, headed by Sergio Poretti and Tullia Iori at Rome Tor Vergata University.

1 INTRODUCTION

During the years of Reconstruction and the economic miracle, many dams were built in Italy for the production of electricity. As often happens in the history of Italian engineering, some of them take on a unique character and identity, recognised on the international scene: these are those designed by Claudio Marcello.

Marcello even gave his name to a type of dam. It rarely happens that a structural type is named after the engineer who invented it. We know the Maillart bridge, the Gerber chair, the Vierendeel beam: and then there is the Marcello dam, a hollow gravity dam.

Marcello is almost unknown among non-specialists, but his work was a world reference in the '50s and '60s and quietly contributed to the success of the Italian School of Engineering: he therefore deserves to be "rediscovered".

2 THE BEGINNING

Claudio Marcello was born in Forlì on 24 February 1901. In 1924 he graduated in Civil Hydraulic Engineering in Pisa and moved to Milan, where he started working in the design office of Angelo Omodeo, a pioneer in hydroelectric technology.

In those years it was increasingly clear that without energy there could be no development, but Italy was without coal and without oil. This is why "white coal", water, was the only valid alternative resource at that moment. It was necessary to use the many rivers of the peninsula: Omodeo was one of the first theorists of the "basin plan" which proposed the exploitation of several hydrographic basins, especially the mountain basins, in a coordinated way.

Marcello's apprenticeship in Omodeo's employ began abroad, in the Soviet Union, where the firm offered consultancy to exploit Russia's great water resources. Then, when the Italian friendship with the Soviets ended, Marcello worked on projects in Ethiopia. In 1937, the turning point: Omodeo retired for health reasons, closed the firm and Marcello was hired as director of Edison's Hydroelectric Plant Construction Office.

Founded in 1882, the Edison Company, with its subsidiaries, was the largest electricity production company in Italy in those years: it competed with Sade (Società Adriatica di Elettricità – Adriatic Electricity Company), Sme (Società Meridionale di Elettricità – Southern Electricity Company) and Sip (Società Idroelettrica del Piemonte – Hydroelectric Company of Piedmont).

At Edison, Marcello made his career until 1963, designing more than 30 dams in Italy in about 25 years and about ten abroad: an incredible number justified only by the parallel, enormous development of the sector, between the end of the war and the economic miracle, when the country started its industrialisation process and was hungry for energy.

Then, from 1 January 1964, with the nationalisation of electricity sanctioned by law in 1962 and the establishment of Enel – Ente nazionale per l'energia elettrica (National Electricity Agency), all private electricity industries were absorbed by the Italian State. Dams and power stations were expropriated and, with the compensation, the companies invested in something else: the Edison company merged with the Montecatini company creating Montedison, active in chemistry, Sip dedicated to telephony and Sme to the food industry while Sade was overwhelmed by the Vajont disaster.

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Marcello became Enel's operating consultant, then in 1967, he left due to age limits. He died two years later, on 9 January 1969, and with him the identity of Italian dam design (Figure 1).

3 THE "MARCELLO TYPE" HOLLOW GRAVITY DAM

The first works that Marcello undertook for Edison before the Second World War concerned the Agaro and Morasco dams, built by the Umberto Girola company: these dams were the most widespread "massive gravity" type. Later, Marcello also designed arched dams, including that of Santa Giustina, on the Noce River, in the Val di Non, in Trentino, built between 1946 and 1950, 152 metres high: the highest in Europe at the time of construction.

Figure 1. Valle di Lei dam on the Reno di Lei River, arch-gravity, double-curvature, preliminary model of wood at Ismes, scale 1:66, 1957 (SIXXIdata: Historical Archive of Ismes).

His curriculum also included double curvature dams such as the spectacular one in the Valle di Lei, above Chiavenna, right on the Italian-Swiss border, built between 1957 and 1960. The model, prepared on a scale of 1:66 at ISMES – the Bergamo Institute specialising in tests to verify the very complicated static characteristics – looked like a sculpture, with a dynamic and elegant line. In reality, it is gigantic: 690 metres long, 143 metres high, much higher than the Pirelli skyscraper in Milan and 10 times longer.

Paradoxically, however, it was not the arched dams or the double curvature dams, even so majestic, that made Marcello famous throughout the world, but those of his invention, the "Marcello type" dam and then the concrete block dam, patented in 1954.

What does a Marcello dam, a special version of a hollow gravity dam, look like?

When Marcello began to work for Edison in 1937, Italy was under Autarchy, that regime of self-sufficiency that was Fascism's response to the sanctions of the League of Nations for the invasion of Ethiopia (Figures 2, 3).

It was therefore, above all, necessary to save materials and Marcello imagined a gravity dam, like the classic ones, and to optimise the use of concrete he emptied it inside. Then, instead of using the classic rectangular triangle shape, his dam became an isosceles triangle. In this way, the water, which pushes on the upstream face, surmounts it and then stabilises it. Marcello had only played with geometry: his isosceles and hollow dam, however, was very advantageous, both from a static and economic point of view. Compared to a traditional gravity dam equivalent, concrete savings can reach up to 30%, with a savings of about 20% on construction costs. It was a little more difficult

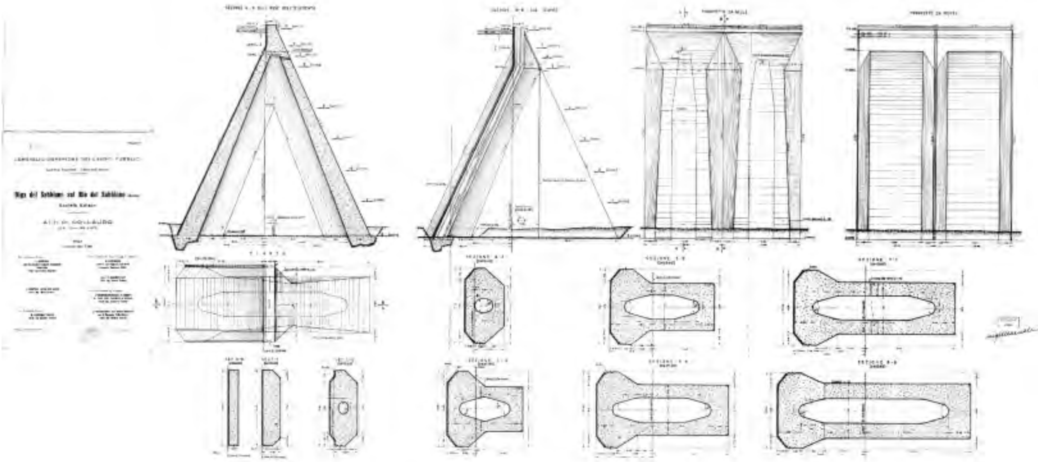


Figure 2. Detail of the hollow elements of a gravity "Marcello type" dam. Sabbione Dam in Val Formazza (SIXXIdata: Historical Archive of Ministry of Infrastructures and Transport, Dams repository).

Figure 3. (On the left) Hollow elements of a gravity “Marcello type” dam. Ancipa Dam on the Troina River, 1949–52; (on the right) Hollow gravity “Marcello type”, Bau Muggeris Dam for the Upper Flumendosa River plants, 1948–49. View from valley (SIXXIdata: Claudio Marcello Private Archive).

to do but it was better this way as the construction site employed more workers.

But that was not enough. Marcello trimmed everything carefully to reduce waste. His dam was made by placing, one after the other, many equal buttresses, each about 20 metres thick. Each buttress was shaped with the minimum amount of material and the walls were reduced in thickness – tilted and enlarged only where necessary. The side facing the mountain, then submerged by water, remains simple and smooth; the downstream slope, instead, is the facade of the dam. Marcello worked its image, sculpted it, and bent it: the result is the fortified wall of a city, with its bastions, towers, battlements. A fortress of water: it is a masonry image, powerful, saturated with history. But, in reality, it is also a futuristic form with a visionary flavour: in the sequence of the very high buttresses, Antonio Sant’Elia’s drawings materialise, in particular the 1913 studies for the power stations and dams, in which engineering, vision, energy and lyricism are mixed together. Futurism, in fact, was nourished by engineering, and engineering, with Marcello’s works, returned.

In the post-war period, before facing the most demanding works, Marcello made a “first test” of his invention in Sardinia, where the production of hydroelectric energy was still largely entrusted to the Santa Chiara Dam over the Tirso River, designed by Omodeo and Luigi Kambo and completed in 1925. Even before the war, it was decided to build a plant in the province of Nuoro, barring the Flumendosa River. Marcello retrieved the old projects for the plant but completely redesigned the dam, which became a hollow gravity Marcello type: the Bau Muggeris Dam, built between 1948 and 1949 by the Lodigiani Company.

Then he also designed one for Sicily, on behalf of Ese (Ente Siciliano di Elettricità – Sicilian Electricity Agency), a public institution founded in 1947, (Figures 4, 5) which had a concession for the hydroelectric exploitation of the island’s rivers. One of Ese’s most ambitious projects planned the exploitation of the Salso and Simeto basins, thanks to a series of dams: the first to be built was the Marcello dam at Ancipa on the Troina River. The work is much more monumental than the Sardinian one: 108 metres high. The construction site, complicated but very well organised by the Lodigiani Company, which specialised in hollow gravity solution, began in September 1949 and, despite the enormous workload, ended in November 1952.

In the same year, 1949, on the northernmost tip of Italy, the construction of the Sabbione Dam, this time entrusted to the Girola Company, also began. The dam is located at 2500 metres above sea level and bars the basin of a glacier that is always full of snow during the winter. The works could only be carried out during the summer season, between the beginning of June and the end of October. The construction-site houses for workers were so isolated that those were donated, at

Figure 4. The hollow gravity "Marcello type" dam at Malga Bissina on the Upper Chiese River, 1955–57. View from the valley, in construction and completed (SIXXIdata: Claudio Marcello Private Archive).

the end of the works, to a laboratory for the observation of cosmic rays thanks to which Carlo Rubbia, later a Nobel Prize laureate in Physics, carried out a part of his graduation thesis.

The construction of this "dam on the glacier" was recounted by the very young Ermanno Olmi, later a famous film director, in a 16 mm documentary shot for Edison. His mother worked at Edison Company

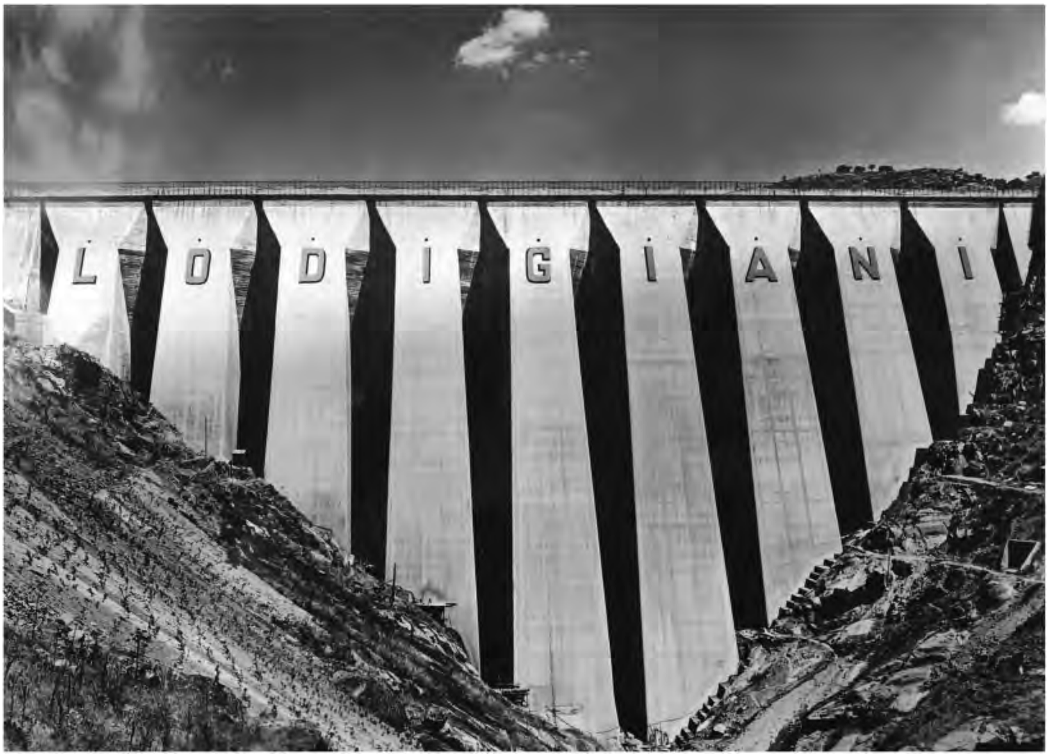


Figure 5. The hollow gravity “Marcello type” dam at Ancipa on the Troina River, 1949–52. View from the valley (SIXXIdata:Claudio Marcello Private Archive).

and, on her intercession, he was hired, still a student, as an errand boy; then Edison entrusted him with the film projections for the workers and, from there, he found a way to shoot company films at the construction sites. There are even two documentaries about the Sabbione Dam, each ten-minutes long, produced at different times: one more amateur, the other with original music written by Pier Emilio Bassi and narrated by a professional reader. Olmi focused on the human side of the site, populated by workers from every region of Italy, who lived for months in the high mountains, far from their families. And while he was fine-tuning his original cinematographic poetics, he gave us a very precious document on the ways of construction.

By 1962, Marcello had built seven more hollow gravity dams. Three dams on the Lombard peaks of Val Camonica, including that of Pantano d’Avio, built by the Salci Company, one of the highest Italian reservoirs above sea level, and the Venerocolo Dam, during whose construction site, in a winter break, Olmi sho (Figure 6) his first 35 mm film, *Il tempo si è fermato* (Time stood still), whose protagonist is the dam guardian. Then, for the Società Idroelettrica dell’Alto Chiese (Hydroelectric Company for the Upper Basin of the Chiese River), the small Malga Boazzo Dam and the Malga Bissina Dam. The latter, with a length of 561 metres and a height of 87 metres, is one of the most evocative wide valley dams in the world, naturally thanks to the magnificent landscape.

Then three “Marcello type” dams were also built abroad: one in Brazil, one in Greece and one in Spain, the Alcantara Dam, which created the largest artificial lake in Europe.

4 THE CONCRETE BLOCK DAM

Marcello, meanwhile, learned that there were geological situations in which his dam was not suitable: especially when there were weak, compressible soils that could be deformed in a differential way. For this reason, on 4 February 1954 he filed a patent to protect the rights to a new concrete block dam.

The cubic blocks, 4 metres on each side, were thrown one on top of the other to form a vertical pile and then a triangular shaped element is generated by joining several piles of different heights. At a distance of 12 centimetres, another triangular element is thrown into blocks. A layer of gravel was placed in the gap, which acted as a lubricant and allowed the dam to adapt to ground differential movements without breaking. The site photos of these dams, with the huge blocks on top of each other, look like scenes from a film about the

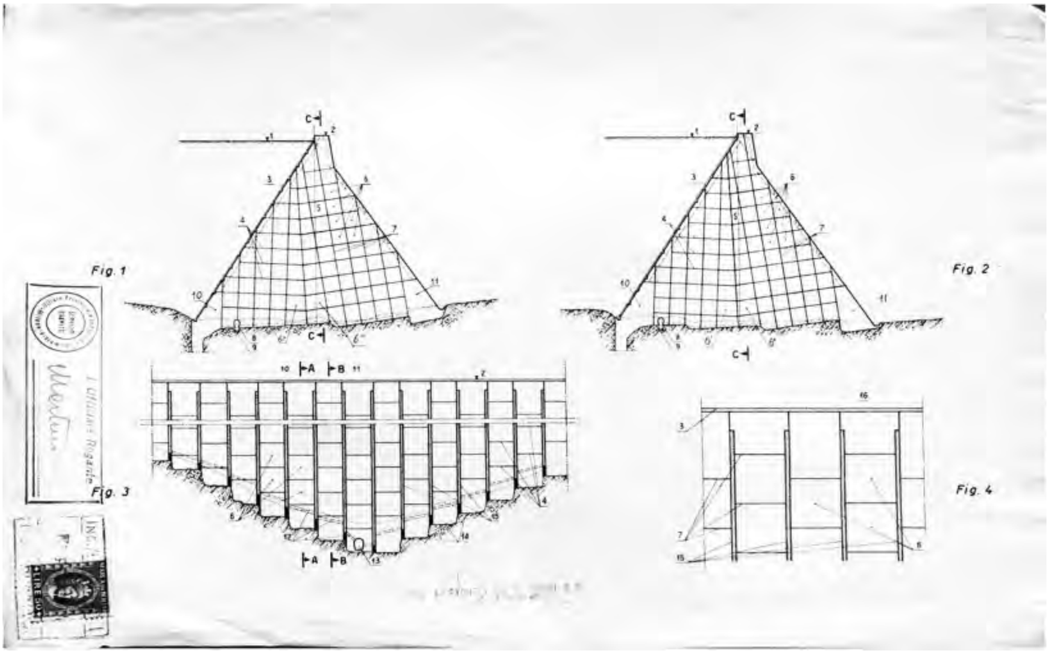


Figure 6. Patent no. 512970, Claudio Marcello, Milan, "The concrete block dams", 4 February 1954 (SIXXIdata: National Central Archive, Patent Fund).

Figure 7. Concrete blocks during the construction site of the Pian Palù Dam in the Noce Valley, 1954–59 (SIXXIdata: Chiolini Photographic Archive).

pyramids or a documentary about the construction of the cyclopean walls of some ancient city (Figures 7, 8).

Once the heart of the dam was finished, Marcello carefully hid the blocks behind the two faces: the upstream one, against the water, is covered with very pure iron sheets to guarantee the seal and avoid corrosion; the downstream one, the "facade" of the dam, is designed with a very modern texture, engraved with deep chamfers. Looking at it from afar, it looks like a punched card, one of those appearing with the first computers, which, in a sort of machine language, speaks to us of pressure, capacity, and energy. In short, a passion for history, vision and the ability to create design objects at the scale of the landscape: Claudio Marcello is a perfect spokesman for the Italian School of Engineering.

Between 1954 and 1958, Marcello built four concrete block dams, three in Italy and one abroad, in Latin America. The first is the one on the Plàtani River, which creates the Fanaco Lake in Sicily, completed in 1955. Not far away, the Pozzillo Dam on the Salso River, also used as a reservoir for the irrigation of the whole plain of Catania.

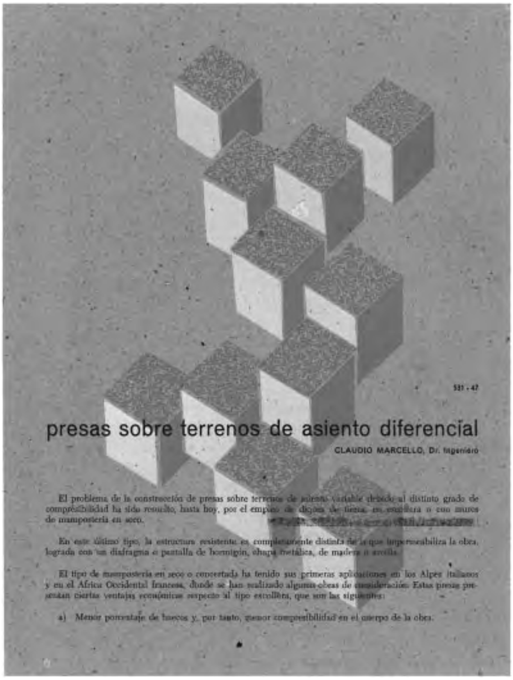
Here too, a documentary produced by Incom (Industria Corti Metraggi Milano – Short Film Industry in Milan), directed by Vittorio Gallo, followed its construction step by step: a film with Neorealist poetics, attentive to the faces and glances of the workers, which described the hard work site without filters and also the dangerous acrobatics which men were forced to perform on the upstream and downstream faces (Figures 9, 10).

In the meantime, the construction of the Pian Palù Dam, in the province of Trento, which barred the Noce River, completed in November 1958, was also underway. And finally, the dam on the Bianco River in Peru.

But soon everything stopped. With nationalisation, the history of hydroelectric power in Italy changed, and investments were interrupted: it was no longer the time, not even for Marcello, to build a dam a year.

Figure 8. Pozzillo Dam on the Salso River in concrete blocks, 1956–58. View from the valley of the completed dam (SIXXIdata: Claudio Marcello Private Archive).

Figure 9. Platani Dam in concrete blocks, 1953–55. Construction site view of the upstream face (SIXXIdata: Claudio Marcello Private Archive).



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presas sobre terrenos de asiento diferencial

CLAUDIO MARCELLO, Dr. Ingeniero

El problema de la construcción de presas sobre terrenos de asiento variable debido al distinto grado de compresibilidad ha sido resuelto, hasta hoy, por el empleo de diques de tierra, en escollera o con muros de mampostería en seco.

En este último tipo, la estructura resistente es completamente distinta de la que impermeabiliza la obra, lograda con un diafragma o pantalla de hormigón, chapa metálica, de madera o arcilla.

El tipo de mampostería en seco o concertada ha tenido sus primeras aplicaciones en los Alpes italianos y en el África Occidental francesa, donde se han realizado algunas obras de consideración. Estas presas presentan ciertas ventajas económicas respecto al tipo escollera, que son las siguientes:

a) Menor porcentaje de huecos y, por tanto, menor compresibilidad en el cuerpo de la obra.

Figure 10. Extract from the journal, *Informes de la Construcción*, April 1960 (free on Internet).

5 CONCLUSION

The years of the dam boom in Italy were the same years in which the Italian School of Engineering became the most famous in the world. These were the years in which Pier Luigi Nervi, Riccardo Morandi and Silvano Zorzi designed the Autostrada del Sole, and in which the Rome Olympics were held.

Eduardo Torroja was among Marcello's leading supporters: in April 1960, the issue of *Informes de la Construcción*, the journal he directed at that time, was entirely dedicated to Italy and included concrete block dams by Marcello along with the works of Pier Luigi Nervi, Riccardo Morandi and Gino Covre.

The great successes of Italian structural engineering were promoted, among others, by a famous exhibition held in New York, at MoMA – Museum of Modern Art – in the summer of 1964, celebrating the world engineering of the 20th century. In that exhibition, in which many Italian works were exhibited, there were also 25 great dams from all over the world, from China to the United States, from Switzerland to France, which represented world excellence. As many as four were "Made in Italy" and signed by Claudio Marcello: the Ancipa, Malga Bissina, Pozzillo and Valle di Lei dams. Certainly a wise selection, perfect to tell the story of the "Italian Style" dam!

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Un metro lungo cinque, 1961. 23'. B/W. Director: Ermanno Olmi, text: Tullio Kezich, voice: Romolo Valli and Alfredo Danti, original score: Pier Emilio Bassi.

History of Construction Cultures – Mascarenhas-Mateus & Paula Pires (eds)

Visionary engineering between utopia and futurism: Italian structures beyond borders after World War Two

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ABSTRACT: In the framework of the SIXXI project, on the history of structural engineering in Italy in the 20th century (ERC Advanced Grant, PI Sergio Poretti, Tullia Iori – www.sixxi.eu), the authors of this contribution dedicated specific research to the dissemination of Italian structural engineering beyond Italy's borders after the Second World War. During that period, the opportunities abroad seemed to grow for construction companies. Instead, as a result of this research, it has emerged that apart from Pier Luigi Nervi, the most famous designers of the "Italian School of Engineering" were not at ease in the international market, rarely seizing opportunities for construction. In this context, a trend attracted attention and represents the specific object of this paper, namely, the design of visionary and futuristic structural solutions that were sometimes even utopian and megalomaniac.

1 INTRODUCTION

In the fifties and sixties structural engineering in Italy was in its golden age. Buildings and infrastructure realized during the Reconstruction of the nation after the Second World War and the subsequent economic boom were appreciated worldwide (Iori & Poretti 2016).

Due to this success, for the economic development of Italy and also for the progressive opening of the international market following the collapse of colonial empires, the opportunities abroad, both for practitioners and for national construction companies, increased. Italians generally remember the period between the mid-50s and the beginning of 90s, when a large scandal known as "Tangentopoli" overwhelmed businesses and public administration, as the period in which their countrymen undertook a lot of construction projects worldwide. For this reason, the export of Italian engineering abroad deserved special study by the authors within the context of the broader research project "SIXXI–XX Century Structural Engineering: The Italian contribution" (ERC Adv. Grant, awarded to Sergio Poretti and conducted by S. Poretti and Tullia Iori at the University of Rome "Tor Vergata", www.sixxi.eu.). The project aims to place the origin, development and decline of the Italian School of Engineering in an historical perspective (Iori & Poretti 2014).

The authors of this contribution examined the international activities of companies and designers to elicit the characteristics of the dissemination of Italian engineering abroad. Thus, it became evident that apart from the exploits of Pier Luigi Nervi, who after 1960 became the most famous engineer in the world, Italians worked a lot in the so-called Third World and in developing nations, in which companies dedicated to the construction of large dams and hydraulic engineering works managed to grab a significant slice of the market. However, Italian engineers were almost completely absent in the United States of America, Japan, and in the most technologically advanced countries of western Europe (Capurso & Martire 2020). In these countries, large international engineering companies, prohibited by law in Italy (Capurso & Martire 2015), were dominant, and "pure" engineers, such as Riccardo Morandi, Sergio Musmeci, and Silvano Zorzi, were mostly unknown and were elaborating proposals that were impossible to build. Instead, those designers, often architects, who tried to export an artistic interpretation of the "Italian Style" structure, such as Paolo Soleri, Vittorio Giorgini and Dante Bini, attracted the curiosity and interest of critics.

This essay is dedicated to the structural inspiration – visionary, futurist or utopian – of these figures abroad, placing them in the context of the history of Italian engineering beyond the borders of Italy.

By analyzing the works of these engineers and architects, the aim of this study was to understand whether the projects presented certain characteristics of Italian structural engineering in these years, what factors were involved in the international interest gained by the architects, and why the engineers were not as successful as the architects (Figure 1).

2 STATE OF THE ART AND METHODOLOGY

The works used for analysis are documented, in part, by publications of the time but have also been the

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subject of recent studies. In the latter, however, interest in individual designers prevailed, justified by the eccentricity of some of them with respect to the main and more orthodox trends in international engineering and architecture. Yet, their contextualization in the history of Italian engineering abroad was not identified. To achieve the objectives of the research, the typical tools of the history of construction have been used even though unbuilt projects were also the objects of analysis.

Obviously, no site documents or construction contracts related to unbuilt works exist. Interactions between architects, engineers and contractors in the design process, especially with regard to the structural conception of works and their construction solutions, were therefore of particular interest to the authors. To understand these relationships, the authors examined the bibliography of the time in addition to letters, tender documents and working drawings kept in archives of designers, construction firms, public and private bodies.

Figure 1. Third mainland bridge over the Lagos Lagoon, S. Zorzi, 1976–80 (Inco Archive, Milan).

Starting from the results of the investigations on the single works, the research linked the experience of the designers and their ideas with the history of the Italian School of Engineering, reconstructed by the SIXXI project.

3 MISUNDERSTOOD MASTERS

After the 1960 Olympics, Pier Luigi Nervi became the “archistar” to whom, everyone on five continents, including important public clients, private institutions, real estate companies, large construction firms and famous architects, turned to for the most diverse works, yearning for projects characterized by his unmistakable signature. After his success in the competition for the bridge over the lagoon of Maracaibo (1957), Riccardo Morandi became a national icon and used his sudden fame to try to spread the so-called “Morandi type bridge” with homogenized cable-stayed trestles everywhere (Fernández Troyano 2013) (Figure 2).

None of the other Italian engineers was able to equal his achievements. To remain among the masters of the Italian School of Engineering, Silvano Zorzi and Sergio Musmeci participated without success in international competitions and rarely had their projects realized (Figure 3).

In fact, after examining Zorzi’s activity, how he managed to complete very few works abroad emerged, which certainly do not stand out in his oeuvre: the port warehouses in Lagos (1963–6), the anonymous viaduct over the Ebro River in Amposta, Tarragona (1964) designed by Zorzi in conjunction with the Spanish engineer Francisco Diaz Amezqueta for the EFYC (*Empresa financiera y constructora*) in Madrid, the

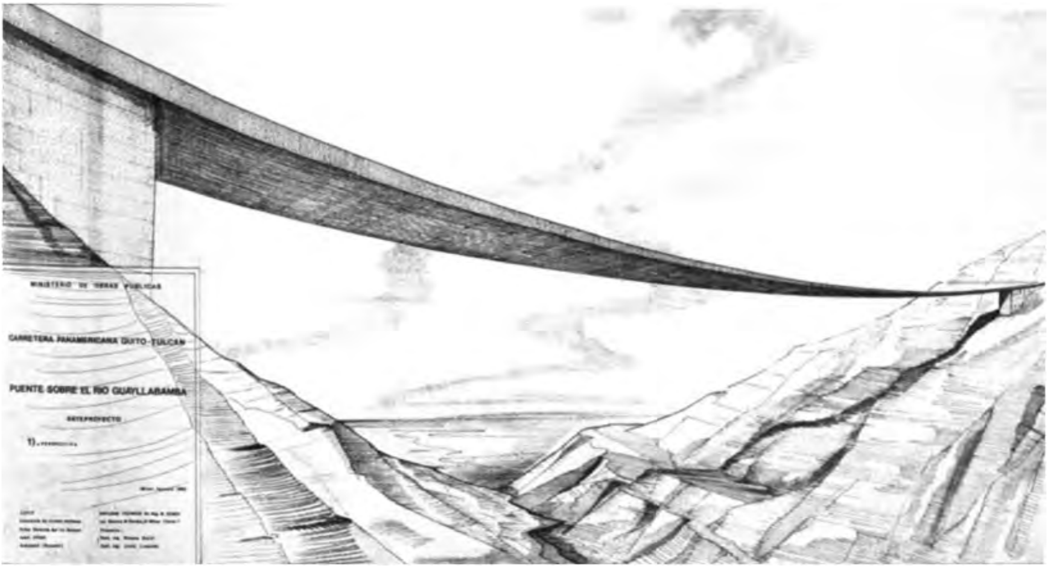

Figure 2. Project for the bridge over the Guayllabamba River, S. Zorzi, 1968 (Politecnico di Milano, Zorzi Archive, Milan).

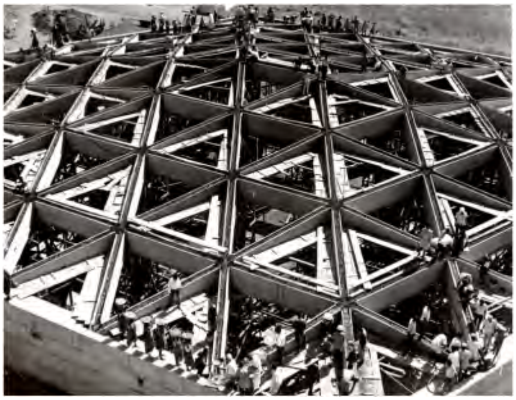

Figure 3. Auditorium of the Atomic Research Centre, Trombay, S. Musmeci, L. Calini, E. Montuori, 1960–1 (MAXXI, Montuori Archive, Rome).

bridge over the Benue in Makurdi (1975–9), and the long third mainland bridge over the Lagos Lagoon (1976–80), both in Nigeria.

Musmeci, on the other hand, would have willingly experimented with innovative static configurations everywhere despite the unavoidable difficulties of execution and the unsuitability of the local workforce to carry out such complex works. The networks of reinforced concrete beams, for example, which was one of the engineer's main research themes, made their first appearance in a project built in India, which was the roof of the auditorium of the Atomic Research Centre in Trombay (1960–1), near Bombay, designed by Musmeci, Leo Calini and Eugenio Montuori together. The auditorium is unfortunately one of the few works created by Musmeci together with the Italian pavilion at the Osaka Expo (1968–70) but it was made of steel and designed by Studio Valle architects. For the other projects, Musmeci's archive is full of projects that were too sophisticated for developing countries for which he designed them and never convinced the financiers.

In the manifest impossibility of realizing abroad the "sculptural structures" that made Italian engineering unique, the international projects by Zorzi and Musmeci that are most worthy of note certainly remain the "visionary" ones.

Zorzi in collaboration with Lucio Lonardo conceived an impossible project for the bridge over the Guayllabamba River (1968) in Ecuador. The bridge would have been a "taut ribbon" of prestressed reinforced concrete, just 30 cm thick, suspended between the two banks, 300 m apart, and the shape based on the geometry of a catenary with a reduced dip. The solution, without precedent (Conzett 2019), envisaged a maximum gradient of 8%, which was an audacious choice that maximized the strength of the materials to be used but was compatible with vehicle traffic.

The deck, to be built with sheathed cables and then injected to form the support and prestressing reinforcement, would then have been completed in segments, cast with a special falsework, and then prestressed transversely. An excess ballast when removed would have allowed further prestressing of the concrete after "releasing the slow deformations suffered by the cables". As a result of this complicated procedure, the elegant, lightweight structure created would have introduced a "practically irrelevant disturbance" into the landscape and would have offered itself to the vehicles in transit in a play of perspectives due to the long, slight elevation connection (Villa 1995) (Figures 4, 5).

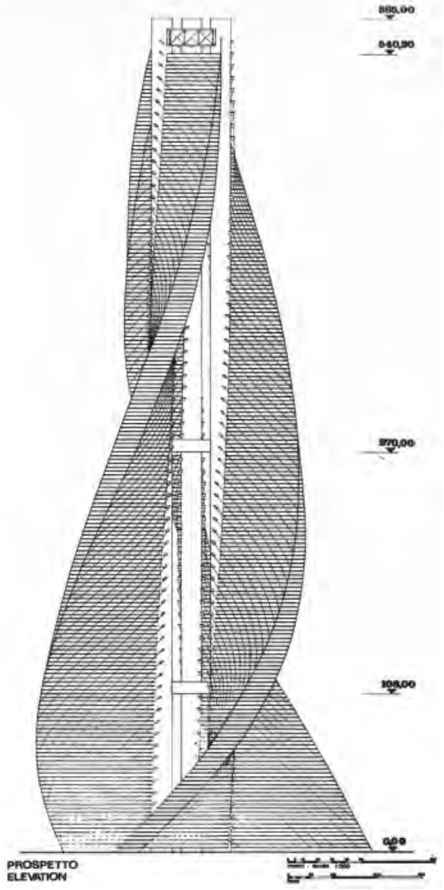

Figure 4. "Helicoidal skyscraper" project for New York, S. Musmeci, M. Nicoletti, 1969–73.

Musmeci, for his part, presented a very modern "helicoidal skyscraper" project for New York (1969–73) that was designed in conjunction with architect Manfredi Nicoletti. Nicoletti contacted the engineer searching for a credible structural solution for the building which, screwed onto itself, should have reached the dizzying height of 565 m in lower Manhattan with floors hanging from a system of ropes. Musmeci had just devised an impressive 3 km single-span solution for the 1969 competition for the bridge over the Strait of Messina based on the principles of tensile structures. The helicoidal skyscraper designed by these two was supported by three circular pylons

Figure 5. “The Beast”, P. Soleri.

that suspended the decks with a series of inclined cables that were arranged along the façade according to a helical geometry. The cables pre-compressed the floors against the pylons and kept them in balance, similarly to the decks of a cable-stayed bridge, while the singular overall geometry was obtained by using a pair of boundary cables for each of the three series of floors that depart from the core. The dynamism of the volume and the plan based on a series of spirals bring the project closer to Futurist and kinetic art, which in those years aroused interest in Italy due to the work of figures such as Bruno Munari, Enzo Mari, and the members of Gruppo T.

At the same time, the skyscraper with its original structural conception but also for the attempt to launch the challenge to the great international steel structures can be considered an original product of the Italian School of Engineering and at the same time, the swan song of the “Italian Style” skyscraper (Capurso 2020).

4 STRUCTURAL FASCINATIONS

In the years in which the school reached its maximum international fame, some Italian architects, moved permanently abroad or in any case, worked outside the national borders, trying their hand at daring structural “suggestions”, sometimes pushed to the utopian. They awakened the curiosity of contemporaries. These architects were eccentric designers, with strong artistic approaches, and were often in voluntary exile because they were unappreciated in their homeland, but hanging on to their famous compatriots’ coattails in those countries that remained taboo for the most orthodox engineers.

Among these artists of the structure, it is certainly worth mentioning Paolo Soleri who was born in Turin and moved to Arizona after World War Two. While in Arizona, he proposed the use of reinforced concrete of minimal thickness that was modelled to obtain form-resistant, unusual shell structures. The theme of thin vaults pervaded all engineering in that period, but Soleri explored it in a very personal way. The book *The Architecture of Bridges* by Elizabeth Mock, published by MOMA for the exhibition with the same name in 1949, made the bridge project called “The Beast” famous. It was developed during the architect’s (and Mock’s) stay in Taliesin West at Frank Lloyd Wright’s school. Soleri conceived the tubular structure as a shaped shell with a double curvature that closed at the top at the centreline which opened towards the supports with two folded wings. The bridge aroused such interest that years later it was also presented in the 1964 MOMA exhibition “Twentieth Century Engineering”. Beyond the effective perspectives, which showed the sinuous shape of the bridge fluidly enveloping vehicular traffic, Soleri also tried to illustrate the construction process of the structure, in which he used an internal steel skeleton as is done in a Melan system.

Given the complexity and the large size of the bridge, he hypothesized the construction of a welded metal cage that was installed on a scaffold and equipped with protruding anchors to attach a network of prestressed cables. High-strength sprayed concrete had to cover the whole to generate a continuous monolithic shell. The solution is of great visual impact but inevitably lacking in depth both from a static and construction point of view; this solution attracted criticism from Nervi, who highlighted the evident uneconomic nature of the construction already in 1959 in a famous article in *Casabella* (Nervi 1959). Nevertheless, the idea attracted the curiosity of some clients for a while longer. Republished in the late 1950s in a German magazine, Soleri’s project was in fact noticed by the Luxembourg Minister of Public Works. He asked the Director of the Grand Duchy’s Department of Bridges and Roads to study the original solution and verify its potential application to the planned Grande-Duchesse Charlotte Bridge that was to be built over the Alzette River (1958), a stone’s throw from the city centre.

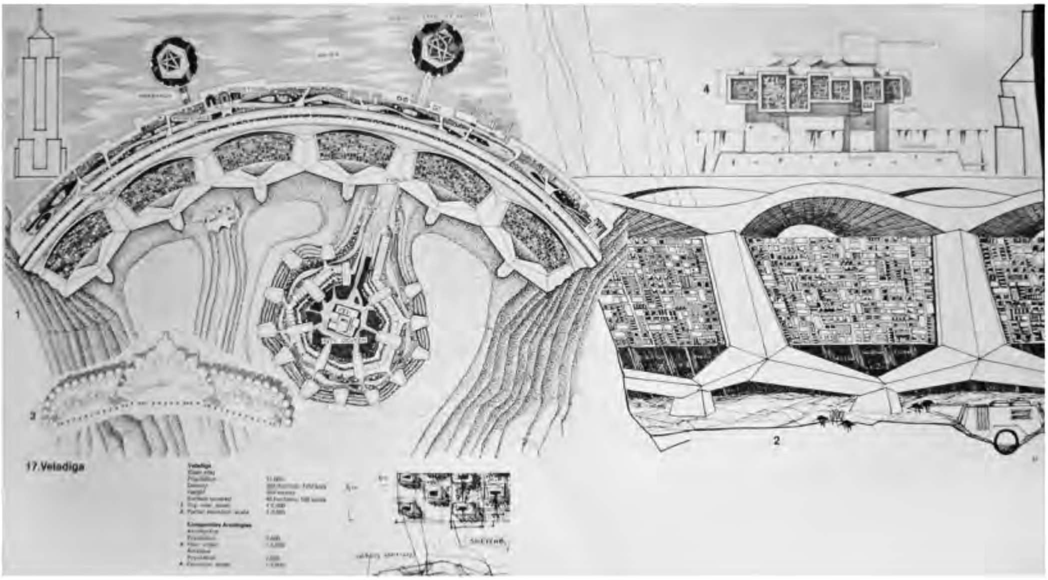

Figure 6. “Veladiga”, drawing in P. Soleri 1969.

Subsequent technical studies soon demonstrated, however, the excessive expenditure associated with the construction method envisaged for “The Beast”. Soleri took part in the design competition that was subsequently published for which he developed seven different solutions, each one more extravagant than the other. The large European construction companies which took part in the competition proposed feasible solutions and the tender committee chose a frame bridge with inclined legs (Kinnen 1964).

In the 1960s, after a brief and failed attempt to apply his “arcological” theories in Italy and back in Arizona, Soleri devoted himself to experiments on self-sustaining densely populated communities. Among his outstanding “design simulations”, are dams of colossal proportions, such as the “Arcodiga”, 750 m high, which was a macrostructure that was represented by Soleri (1969) and contained designs in futuristic tones, which could incorporate entire pieces of the city.

His ideas were as ambitious as they were unrealistic even more so with the scarce resources and in the simple context of Soleri’s communities, such as Arcosanti. In these communities, only a few buildings of much more ordinary dimensions were finally built. The architect’s speculative activity was aimed primarily at the overall relationship between man and nature, but it is undeniable that the most effective vehicle of his philosophy, which attracted so much interest in France, Germany, and North America, was the stylistic identity of his graphic production (Figure 6).

The tectonic configuration of his designs clearly distinguished him from European or Japanese architects who, in the 1960s and 1970s approached the theme of the cities of the future by hypothesizing “fantastic architectures” that were much more conceptual. Comparing ideas such as Kurokawa’s Helicoids (1961) or Herron’s The Walking City (1964) with Soleri’s projects helps to visualize the differences between Soleri’s structural inspiration and those of other contemporary “visionary” architects. The distance was accentuated by a passion for the themes of engineering works, such as the bridge and the dam, technological austerity, and the obstinate enhancement of craftsmanship in addition to the finished image of its urban units (Lima 2004), most often guaranteed by the form of the structural object. Inverse-geometry shaped pillars, ribs, buttresses, rampant arches, form-resistant shells that were freely drawn on the repertoire of every era of construction and engineering crowded the projects. The drawings were dominated by a triumph of structures, often reasonably symmetrical and made gigantic through a process of radial repetition that produced amazing cement “textures” that were so characteristic of the Italian School of Engineering (Poretti 2017) and destined to house its communities. The work of engineering, “brought to the level of pure representation”, thus became the object of an autonomous reflection, linked to the tradition of Italian visionary modernism of the 1930s (Poretti 2007).

While Soleri developed his projects based on a personal conception of the aims of the transformation of the territory, other experiments carried out by Italians who emigrated abroad focused more specifically on rethinking traditional building methods. Their design line, however, maintained a strong link with reinforced concrete construction and research into shape-resistant structures. At the end of the 1960s, Vittorio Giorgini also arrived in the United States of America. He had built two curious houses on the Gulf of Baratti in Italy, which could be perfect attractions at Disneyland: the hexagonal house (1957) and the Saldarini house (1962). In the latter house, he had experimented with

Figure 7. V. Giorgini, Construction of the “Liberty” recreation centre (BACO, Giorgini Archive, Baratti).

Figure 8. V. Giorgini, Construction of the “Liberty” recreation centre, detail (BACO, Giorgini Archive, Baratti).

the construction of a structure made entirely out of a continuous shell of reinforced concrete or rather, with a system of wire mesh that was shaped according to free geometries and hand-covered with a thin layer of concrete(Figure 7).

With the crisis, a shortage of clients existed in Italy, so Giorgini moved to New York where he became a university professor at the Pratt Institute’s School of Architecture. In 1976, he obtained partial funding to build what was to be his first major American work, that of the “Liberty” recreation centre in New York State. In New York, he tested the large-scale use of the “shell beam”, which was asymmetrical and “not oriented in a mathematical sense”. It was the result of the manipulation of figures composed by intersecting curved surfaces, such as the bull and the sphere (Giorgini 1995). The modelling of the shapes was handcrafted in the open-air workshop of the building site by moulding the mesh of nets with wooden poles that were also used as props and instruments for controlling the geometry. This particular experiment was conducted entirely in the form of self-construction with a group of students and very few means. Although Giorgini’s morphological approach brings to mind current theories on morphogenesis, both architectural and structural, the construction suffered from a lack of the necessary scientific and technological support. A layer of high-strength cement barely 5cm thick had to be laid on the metal mesh, but the unavailability of new funding prevented the structure from being completed. After this experience and in line with the new North American context, Giorgini tried his hand at projects for reticular macro-structures and gigantic steel tensile structures, potentially capable of revolutionizing the layout of entire parts of the city, which also remained on paper.

The same desire to innovate the use of reinforced concrete also characterizes the research of another architect-constructor, Dante Bini, who was the inventor of an original building site technique for building domes. Bini’s aim was similar to Nervi’s 30 years earlier, namely, to eliminate the use of expensive wooden formwork for casting vaulted structures. His reinforced concrete structures were “inflated” on a pneumatic formwork, consisting of a polyvinyl chloride (PVC) membrane, which when filled with air would lift the still unhardened concrete and the reinforcement at the same time (Figures 8, 9).

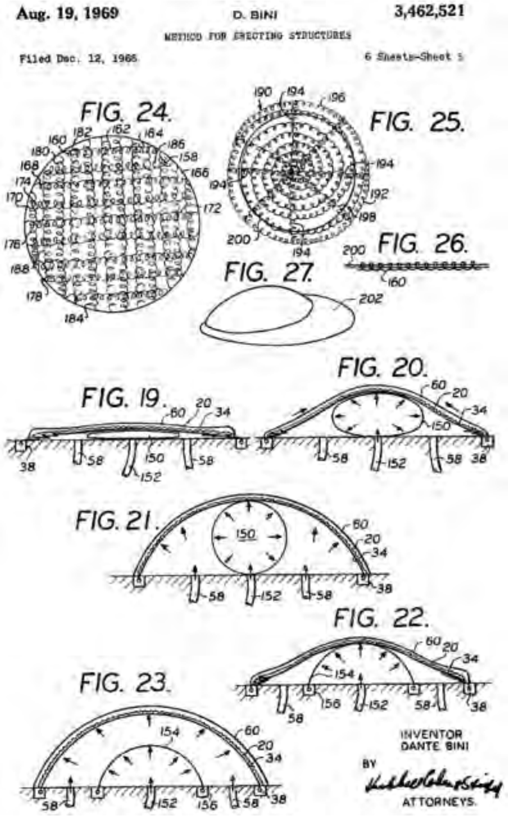

Figure 9. United States Patent n. 3462521, D. Bini, 19 August 1969 (United States Patent and Trademark Office, database on line).

After the first experimental works in Emilia, Bini was invited to Columbia University in 1967 by Mario Salvadori, a professor who had been at the university since 1959 after moving to the United States of

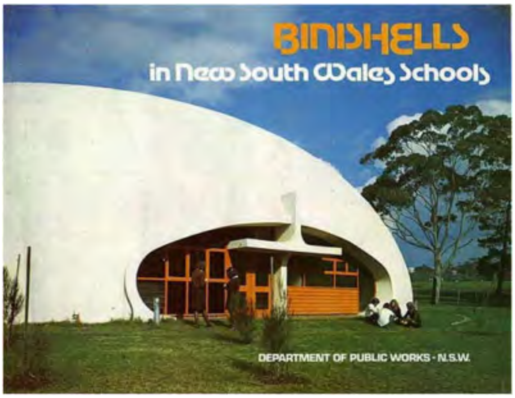

Figure 10. “Binishells in New South Schools”, brochure of the Department of Public Works – N.S.W.

Figure 11. Inflation of a Binishell.

America following the fascist racial laws. Engineer, passionate experimenter, and patron of several Italian designers in the United States, Salvadori allowed him to erect a prototype dome with a diameter of about 15 m on the university campus by organizing an event for the occasion that attracted a crowd of onlookers (Pennacchio & Ricci 2016).

Back in Italy, Bini had the opportunity to realize a villa in Sardinia for the director Michelangelo Antonioni. This villa was his most famous work, but in Italy the chances of experimentation were limited. An interesting professional opportunity presented itself, however, on the other side of the world in Australia. The New South Wales Public Works Department contacted him in 1973 to implement a vast programme of construction of schools, libraries, and other multifunctional education buildings. In the still economically backward hinterland of the Australian country, in which mechanization and automation had not yet revolutionized building technologies, Bini’s system was particularly suitable. In fact, his system made it possible to lift a complete roof quickly, in three weeks at the most, with considerable advantages in terms of costs compared to traditional techniques (Figures 10, 11).

The execution procedure involved the construction of the perimeter foundation beam in the form of a ring on which the pneumatic membrane in neoprene reinforced with nylon was fixed. Steel helical springs and reinforcement bars were arranged on the membrane in a predefined manner, all anchored to the circular foundation beam. The helices did not have a specific structural function but allowed for both the control of the elevation and the shape of the dome while it was inflated and for the correct positioning of the reinforcement rods, which were inserted in the spirals. A thin layer of concrete, containing retardant and plasticizer additives, was then cast onto the still flat membrane. Finally, a light PVC sheet, also fixed to the anchor beam, covered the conglomerate. The pneumatic formwork was then inflated within a day or two, depending on the diameter of the dome, and lifted conglomerate and bars (Morelli 1978).

In the end all that remained was to recover the membrane, after deflating it, cut out the openings for the doors and windows and complete the interiors with systems, divisions and finishes. However, it is precisely the “cutting” of the shells, on site, carried out by hand, to make the small domes always different which, at the same time, confutes Bini’s idea of an entirely mechanized construction of the structure. The Australian programme allowed the realization of 21 Binishells up until 1976. The visibility offered to the technology devised by the Italian designer allows him today to count more than 1500 domes built worldwide, including sports facilities, residential and commercial buildings, tourist complexes and educational facilities, under his patents, while many of Australia’s pioneering structures have been abandoned or demolished (Pugnale & Bologna 2015).

5 CONCLUSIONS

With the exception of the archistar Nervi, the best designers of the Italian School of Engineering were not at ease in the international market. They had to deal with clients with tight financial constraints and builders concerned with reducing risks with simple designs already validated by experience. They obstinately continued to design original works, rarely seizing opportunities for realistic goals.

In contrast, some architects dedicated to structural “inventions” gained visibility in countries that remained taboo for more orthodox engineers. Their activities were illuminated by the successes that Italian engineering had achieved thanks to the structures built in their homeland.

Even if Zorzi, Musmeci, Soleri, Giorgini and Bini were interested in the design of structural forms starting from different assumptions and with different aims, the research has also shown that their “visionary” experiments can be interpreted as a chapter in the history of Italian engineering abroad.

They tell, in fact, how some designers during the years when the client in Italy left less and less space for static experimentation, they tried in a fanciful way to export a way of designing structures that carried in its genetic heritage some “Made in Italy” characteristics: the frequent choice of reinforced concrete as a construction material; the use of the structure in the image of the works, whether small or large buildings, bridges or entire cities; the affinity of many projects with the imagination of futurism or kinetic art; and finally, the stubborn enhancement of the craft dimension of the construction site.

ACKNOWLEDGMENTS

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History of Construction Cultures – Mascarenhas-Mateus & Paula Pires (eds)

Between academy and practice: Adriano Galli and the prestressed water bridge over the Casilina in Mignano Montelungo (1954)

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ABSTRACT: Among the most prolific engineers of post-war Italy, Adriano Galli (1904–1956) stands out as an eclectic figure: researcher, teacher, and designer, he devoted his attention to different static solutions and techniques. He designed stiffened vault bridges and pioneering prestressed concrete structures, such as the pillars for the Castellammare-Monte Faito cableway (1952). An interesting application of prestressing to bridges design is the tubular aqueduct Galli designed to bridge the crossing of the hydroelectric plant Volturno-Garigliano over the Casilina road in Mignano Monte Lungo, Campania. Completed in 1954, the structure consisted in a conduit supported by piers. The duct was prestressed both longitudinally and radially to avoid tensional stresses, which could cause cracking in the concrete surfaces, hence leakage. The bridge in Mignano represented a noteworthy solution, soon disseminated abroad. Analysing the structure offers an opportunity to contextualize Galli's ability in theory, experimentation, and practice.

1 INTRODUCTION

In recent evaluations of 20th-century construction history in Italy, the contribution of a large number of structural engineers has still not received proper recognition. Besides major names like Pier Luigi Nervi, Riccardo Morandi, Sergio Musmeci or Silvano Zorzi, many lesser-known engineers contributed greatly to the creation of the so-called Italian school of engineering, both in the field of theoretical experimentation and in the profession itself (Iori & Poretti 2014–2020). Among them, Adriano Galli (1904–1956) represented a polyhedric figure of engineer, scientist, and professor, who brought prestige to the Neapolitan school of structural engineering. Active in the profession and in teaching, Galli combined theorical research on building science with pragmatical outcomes in structural design.

After graduating from the Scuola Politecnica di Napoli in 1928, Galli soon served as university assistant for some of the most important figures in the history of building science in Italy: Carlo Luigi Ricci (1884–1943), Antonio Signorini (1888–1963) and Giulio Krall (1901–71). He developed a strong mathematical approach during his assistantship for Ricci, whose lessons were collected and edited by the young assistant in a successful textbook (Ricci 1932). In that period, Galli's research focused mainly on theoretical subjects such as the infinitesimal strain theory, which were also presented in scientific papers (Galli 1933). The influence of Krall's pragmatical approach to theory was evident in his research on thin arches and vaults, as well as in his interest in the mechanics of materials. In line with this, in summer 1932 Galli arranged a trip to Zurich, during which he visited the materials testing laboratory directed by Mirko Roš (1879–1962), who was friends with Robert Maillart (1872–1940). The trip surely gave the Italian the chance to see the stiffened vault bridges that Maillart had built in Switzerland. Indeed, that structural solution was soon investigated by Galli, who published several studies on the subject (Galli 1941, 1942, 1956).

On Ricci's death, Galli inherited the course on wood, steel and reinforced concrete at the Faculty of Engineering of Naples. In 1946, he became full professor, and he was also called on to direct the Istituto di Scienza delle Costruzioni of the University of Naples. In the meantime, his experience of Ricci's lessons flowed into Galli's most well-known publication: the *Lezioni di Scienza delle Costruzioni* (*Lessons in Building Science*). Conceived as lecture notes collected around 1945, the work was reprinted in many editions (Galli 1950). Also enriched by the contribution of his students, the *Lezioni* soon became a widely used textbook in Italy promoting the Neapolitan school of engineering. Some years later, the work would inspire Vincenzo Franciosi (1925–89), one of the most talented of Galli's students, in the writing of *Scienza delle Costruzioni* (Franciosi 1965–71), which would make frequent reference to the projects and studies conceived by his master.

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Besides Franciosi, as professor at the University of Naples Galli taught an entire generation of engineers, such as Salvatore Leone (1922–2004), Elio Giangreco (1924–2008), Aldo Raithel (1925–2004), Fabrizio De Miranda (1926–2015), and Francesco Martinez y Cabrera (1929–2000). His academic efforts were recognized with his selection as Dean of the Faculty of Engineering, a position he held from 1952 until 1956, the year of his death. In 1958, a foundation based at the University of Naples was created in his name to promote the study of building science and to support the work of young researchers with scholarships.

2 STRUCTURE DESIGNER

The course of Galli's career within the University of Naples was anything but localist, as testified by his interest in foreign experimentation. Thanks to his international relations, above all with the engineering circles of Switzerland and the United States, Galli succeeded in introducing into Italy new theories and technologies that he soon applied to projects.

For instance, his knowledge of stiffened-vault bridges – the Maillart type – reinforced by his Swiss trips informed the design of several bridges built in southern Italy. Among them, the bridge over the Corace in Gimigliano, Calabria (1955: Figure 1), covered a span of 80 m. A shorter free span of 29.50 m characterized the bridge over the Vernotico in Gragnano, Campania (1956), designed along with Franciosi. The typology of the stiffened-vault bridge was praised by Galli for its capacity of rationalizing the stresses between the vault and the beam. Indeed, calculations could entrust the permanent loads to the vault; meanwhile, faster, accidental loads could rely on the rigidity of a structure with perfect boundaries, which could be regarded as yielding ones in case of temperature variation (Galli & Franciosi 1954, 1955).

The adoption of the Maillart type did not prevent experiments with other statical solutions, such as the beam bridge adopted for the viaduct of Seiano, erected in 1943; and the bridge over the Flumendosa, completed in 1954 (Franciosi 1965–71 vol. 3: 165–70).

Galli's innovative approach arose above all from his confidence with the new technology of prestressed concrete which, although already largely adopted abroad, was permitted in Italy only from 1947 after the release of the *Norme per l'esecuzione e l'impiego delle strutture di cemento armato precompresse* (decreto del capo provvisorio dello Stato (DCPS) of 20 December 1947, n°. 1516). The regulation paved the way for a new method of planning structures (Marandola 2009), which soon inspired Galli, always open to technological feats. Indeed, between the late 1940s and 1950s the Neapolitan engineer employed prestressed concrete in many projects, from the Maurizio Capuano thermoelectric plant in Naples (1948), to the beams of the Metropolitan Cinema in Naples (1948) and the industrial buildings of the Lancia production plant in Naples (1952).

Figure 1. Adriano Galli, bridge over the Corace in Gimignano, Calabria, 1955 (Archivio Storico Enel, ASE).

A particularly pioneering application of prestressing to vertical structures was adopted by Galli for the three pillars of the Castellammare–Monte Faito cableway, completed in 1952 in the Naples area. The three pylons were executed according to a cellular structure in reinforced concrete with a hollow rectangular section, whose thickness varied from 15 to 18 cm. Their shape was modelled based on geometrical and practical reasons: the width was fixed by the distance necessary to separate two cabins on the line; the other dimension, longitudinal to the cables, changed with height, splaying towards the ground according to an exponential curve. The slender structure of the pillars – above all, the first and the third ones, which were taller – had to resist to a series of loads. The loads mainly depended on the sliding of cables and on the action, from several directions, of the wind. In particular, the wind impacted: on the pillars themselves, on the cables, on the cabins, and even on the ribbed platform on top, which supported the elevating mechanism. To avoid tension, the structures were prestressed along the vertical axis according to the "Morandi" prestressing system.

Prestressing the trunk with tendons was an economically convenient solution, also when compared to ballasting. Indeed, ballasting would have produced a natural compression; nevertheless, it would have required a consistent increase in the dimension, with higher load values for the foundations. Instead, the use of tendons allowed a reduction of the section, which granted the accessibility and inspection of the pillars through manholes in the hollow section. The tendons were laid along the entire length of the trunk corresponding with the centre of gravity to reduce the possibility of flections.

The pillars on the Monte Faito attested Galli's understanding of prestressed concrete technology, which he even adopted in the construction of bridges. Indeed, just few years after the Monte Faito project, he designed a prestressed concrete bridge over the Garigliano, on the border between Lazio and Campania (1954).

The structure comprised a continuous beam on a free span of 46 m. In the same years, Galli was completing a far larger prestressed bridge, the Mignano Monte Lungo aqueduct in Campania, one of his last and most inventive structures (Figures 2, 3).

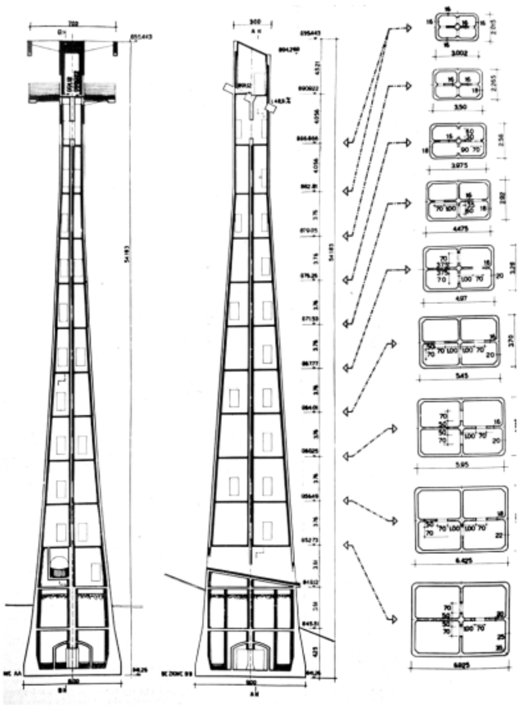

Figure 2. Adriano Galli, sections of the pillars for the Castellammare-Monte Faito cableway, Campania, 1952 (ASE).

3 THE PRESTRESSED AQUEDUCT OVER THE CASILINA

The bridge was among the typologies that best took advantage of the new Italian regulations on prestressed concrete. The success of prestressed bridges was mainly due to the economical convenience of the solution over metallic structures. Moreover, it must be framed within the demands of post-war reconstruction, in terms of infrastructural developments and occupational policies – especially in southern Italy. The first approvals of projects for prestressed bridges dated back to 1949. Among the first to be built, there were the bridge over the Piave (1950) by Carlo Predella; the bridge over the Samoggia (1950) by Giuseppe Rinaldi; the bridge over the Elsa (1950) by Riccardo Morandi; and the bridge over the Mucone (1951) by Silvano Zorzi. These early structures were gradually followed in the early 1950s by a growing number of prestressed bridges, such as the bridge over the Idice by Rinaldi (1952).

Outside Italy, experimentation in prestressing was advanced, as proved by exemplary early structures. As far as aqueducts are concerned, the French engineer Eugène Freyssinet designed an early pre-stressed concrete aqueduct in Oued Fodda, Algeria, back in 1936–37 (on Freyssinet and pre-stressed concrete, see Espion 2012). Around the same time, pre-stressed concrete pipes had started to be used in Italian aqueducts, such as in the aqueduct for the Montecatini plant in Crotone (Guercio 2008: 8–9).

The prestressed aqueduct designed by Galli in Mignano Monte Lungo followed in the footsteps of this experimentation. The structure was part of the Volturno Garigliano hydroelectric plant, built by the Società Meridionale di Elettricità under the direction of the engineers Carlo Drioli and Mario Cuocolo. The hydroelectric grid drew waters from the river Volturno and emptied them into the river Garigliano.

Figure 3. Adriano Galli, aqueduct over the Casilina in Mignano Monte Lungo, Campania, 1952–4 (source: the authors).

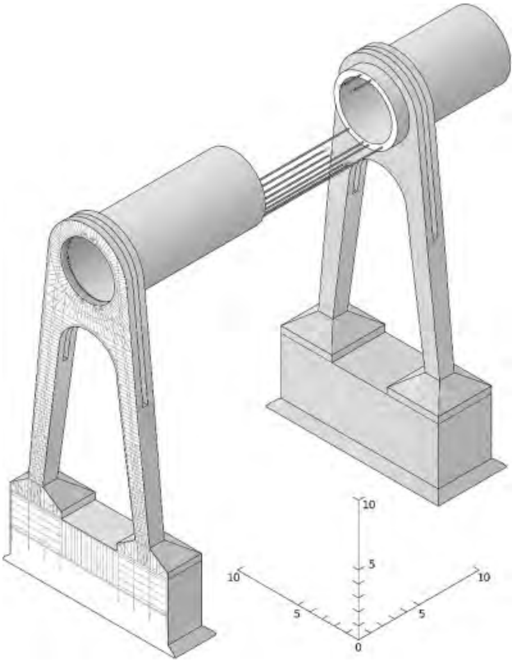

Figure 4. Axonometric section.

Figure 5. The piers in construction (Archivio Storico Enel).

The difference in altitude of about 150 m powered two hydroelectric plants at Rocca d'Evandro and Sant'Ambrogio.

About 2 km before the station of Rocca d'Evandro, the conduits had to cross the state road Casilina in the territory of Mignano Monte Lungo. Adriano Galli was asked to bridge the crossing with a suspended aqueduct, which was calculated with the contribution of the engineers Mario Aprato and Giulio Nicolosi, who oversaw the measurements and experimental investigations (Galli et al. 1954). Construction of the aqueduct, along with the works on the adjoining hydroelectric plant, began no later than 1952. Two years later, in 1954, the structure entered into service.

Its completion offered a practical solution to a series of little investigated constructional themes, such as the position of tendons within a tubular geometry or the question of cold flow, which attested to the scientific novelty of the structure. The choice of a prestressed concrete tube to cross the road was probably also conditioned by the decision to use concrete tubes for the underground trunks.

Indeed, concrete tubes were particularly well adapted to the construction of forced tunnel conduits, allowing a better collaboration with the excavated rocks. Moreover, compared to the cast iron tubes still largely used in other countries concrete ones – and especially those that were prestressed – showed a higher resistance to water and a greater safety factor. In concrete ducts, eventual breakage did not cause sudden explosion but rather cracks which, in case of underground pipes, closed automatically when the internal pression decreased. The major problem in reinforced concrete conduits (and in tanks, too) was leakage through hairline cracks which was often due to tension stress in the section. Prestressing was particularly suitable to overcoming the issue since it exposed the section to compression only, avoiding tension and hence the risk of leakage too.

The structure designed by Galli (Figure 4) comprises a prestressed conduit raised on a height of about 14 m from the road level. The structure was schematized as a tubular beam without bending.

The cross-section of the duct is an annulus with an external diameter of 5 m and an internal one of 4.26 m, which is reduced to 4.20 m with the application of plaster or gunite. The dimensioning was based on a calculated hydrostatic load of 31.25 m above the ridge of the conduit, which was increased, as a safety factor, to a pression of 4 atmospheres. The stress conditions were determined both under the effect of the weight only and under the combined effect of the weight and the hydrostatic pressure.

The conduit is divided into six spans of 24 m each, supported by five piers in the middle and by linear walls at either end where it enters the mountains. The piers were the first elements of the structure to be erected (Figure 5). Each trestle-like pier in reinforced concrete comprises a round arch with splayed supports crowned by a round tympanum (Figure 6). The supports are solid up to a height of 10 m from the foundation extrados. Lines of shadow in the profile of the piers reveal that, from this point on up, they result from the coupling of pierced slabs, hinged to the lower stumps to allow a relative rotation of the upper part. The two pierced tympani, derived from the same pier,

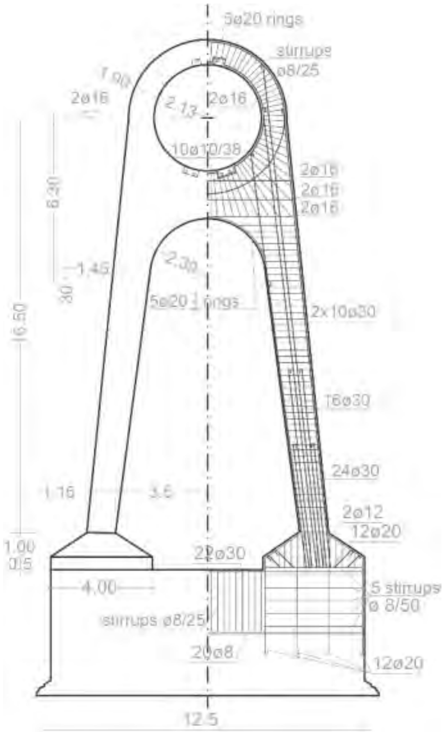

Figure 6. Projection and section of the pier with reinforcement.

work independently for each span. They are contiguous to the adjacent trunks of the duct, with which they constitute a monolithic piece.

The hydraulic continuity between two consequent pieces was solved with the insertion of a reinforced concrete ring with a slightly pentagonal cross-section sealed by waterproof materials (Figure 7).

To counteract tension, the structure was provided with steel reinforcements on the main directions. Moreover, it was post-tensioned longitudinally by steel tendons laid in the direction of the conduit and transversally by hoops arranged at 75 cm from each other. The longitudinal precompression was calculated to obtain a maximum effect in the lower part of the middle section, with a parabolic distribution between the two supports.

The longitudinal tendons were concentrated in the inferior part of the annulus, where the bending moment produces tensional stress (Figure 8). Four strands, made of forty ∅5 mm wires, were placed on the lower section at 4.60 m from one extremity and were tensioned at the opposite end. Therefore, the middle sections were crossed by eight tendons while the sections near the supports were crossed by four tendons only. In proximity of the piers, to balance the tension of the lower part, the upper portion of the section was provided on each side with two shorter tendons, 2.30 m long, made of twenty-eight ∅5 mm wires.

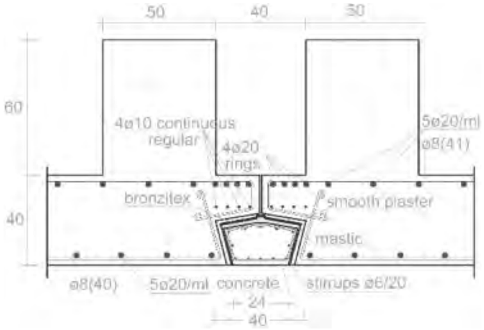

Figure 7. Details of the joint between adjacent trunks.

The longitudinal disposition of tendons did not perfectly solve the issue of shear stress as a helical configuration around the conduit would more efficiently have done. However, it facilitated the prestressing procedure and limited the problem of friction between wires.

The prestressing followed the BBRV system invented by Max Birkenmaier, Antonio Brandestini and Mirko Roš, in collaboration with Kurt Vogt. The patent, released in 1952 by the Swiss company Stahlton SA of Zurich, described a jack with button-head anchorage. It was associated to anchorage provided in the previous BBR patent (1951), by the same company (Cestelli-Guidi 1987: 56; Sanabra-Loewe & Cappellà-Llovera 2014: 114).

In the aqueduct the tendons were drowned in the concrete casting at one end, while they were anchored to a prestressing ring at the other end (Figure 9). The wires were connected to the ring through a mechanical riveting at the end of each wire. Near the anchorage, the sleeves joined in a containing pipe. The anchorage itself comprised a truncated pipe with head drilled by 42 holes, in which the wires were inserted before being riveted with a specific portable machine. Towards the junction of the two spans, the anchorage presented an interior threaded end for the connection to the jack, and an exterior one for the lock nut.

Meanwhile, the ring tension was contrasted by means of hoops placed every 75 cm. Each hoop, made of forty ∅5 mm wires, was enclosed in a sleeve spaced by wooden dowels. The hoops were laid at the extrados of the conduit before the casting.

Once the conduit was cast and the concrete hardened, the hoops were tensioned contemporarily in eight points with prestressing jacks, which produced radial forces. Before downloading the jacks, eight wedges were inserted as spacers in the hollows left during the casting.

The post-tensioning required multiple jacks for a single hoop, so it proceeded one by one. To avoid the longitudinal bending stress – whose value would be maximum when a single hoop was tensioned and minimum when all the rings were tensioned – hoops were tensioned gradually. Starting from one extremity: the first and the second hoops were half-tensioned; the

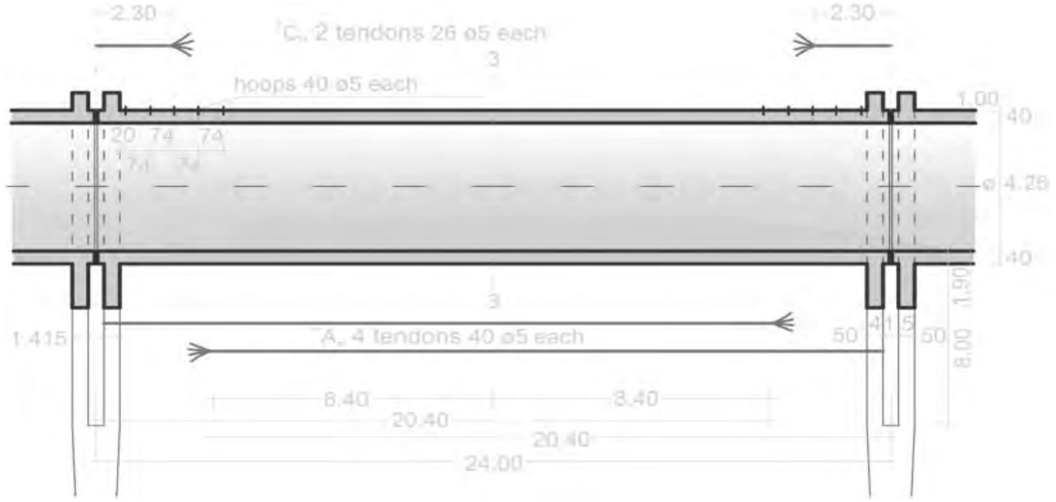

Figure 8. Longitudinal section with indication of the longitudinal tendons and the hoops.

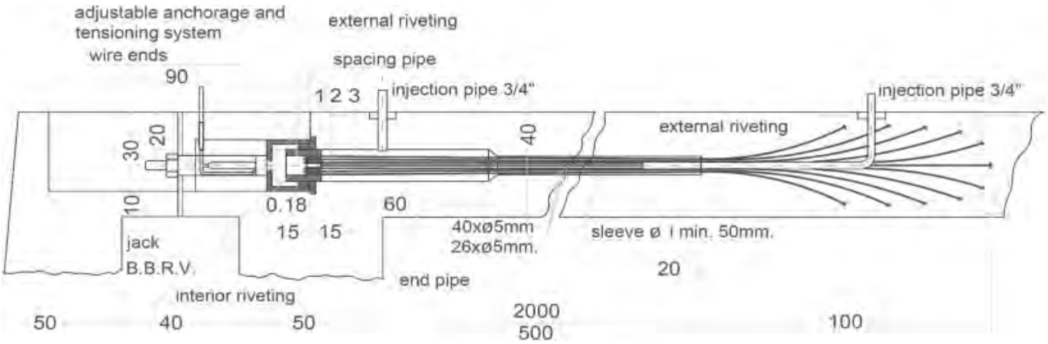

Figure 9. Anchorage of the tendons (BBR system).

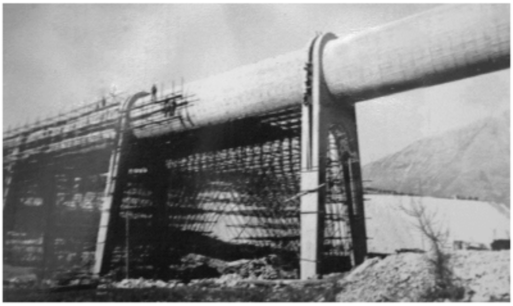

Figure 10. The scaffolding over the Casilina road (ASE).

second hoop was half tensioned; the first hoop was fully tensioned; the third hoop was half tensioned; the second hoop was fully tensioned; and so on, according to the scheme 1, 2-1, 3-2.

The arrangement of the reinforcement and the casting of the tube required the construction of a scaffolding in Innocenti tubes, with a triangular opening in the middle span to allow for the traffic on the road (Figure 10).

Concrete casting was performed continually for each span from April to December 1952. The concrete was compacted with internal vibrators. The concrete mix had a low water-cement ratio, balanced by the addition of a fluidifier. The calcarean gravel used as aggregate for the concrete mixture, selected according to a precise aggregate demand curve, came directly from the River Volturno.

The post-tensioning was executed in two steps – one after 15 days from the casting, the other after 28/30 days – to measure and reduce the loss of tension. Once the structure was completed, the work was tested, both with the empty conduit and in operating conditions. The test measured loads, deformations, and temperature gradients between the interior and the exterior side of the conduit, resulting in acceptable values of creep, as presented by Nicolosi at the 1954 congress of the Associazione Nazionale Italiana del Cemento Armato Precompresso (Nicolosi 1954).

4 CONCLUSION

Designed with pre-stressed concrete, a technology which was cutting-edge for Italy in those years, the future of the aqueduct in Mignano Monte Lungo, as in the case of all pre-stressed structures, is problematic from the perspective of maintenance and monitoring. As the recent chronicles have proved, the main doubt regards the behaviour of materials over time, including a consistent loss of tension and the corrosion of the metallic wires. The material degradation of the aqueduct could worsen in operational conditions, not helped by the fact that the post-tensioned hoops are protected by a layer of concrete which was applied externally to the conduit.

Despite the objective difficulty of maintaining such a complex heritage, the aqueduct of Mignano Monte Lungo is the symbol of a Nation running towards the future, as well as a saviour for an economically depressed region. Its construction employed workers in an area which had been site of many of the cruellest battles of the Second World War, including that of Cassino (1944). The infrastructure embodied a promise of development and economic prosperity for an entire region. Nevertheless, the extraordinary nature of its construction and its promise of hope were stained by a tragic episode.


Figure 11. Interior of the conduit before the casting (ASE).


Figure 12. Carpenters working on the reinforcement (ASE).

On 25 March 1952, an accidental explosion caused the death of 42 men who were working in the penstock of Cannabinols, some 100 m upstream of the aqueduct (De Luca & Fontaine 2012). The dramatic event gave impulse to a new national legislation on occupational safety (see decreto del presidente della Repubblica (DPR) of 27 April 1955, n°. 547 and DPR of 7 January 1956, n°. 164)

Despite the tragedy, the aqueduct was presented in national and international magazines. For instance, it was published in a 1955 issue of *Ultimas Noticias sobre Hormigon Pretenseado*, the bulletin of the Spanish Association for Prestressed Concrete (Galli et al. 1955). The Spanish article, which translated a previous article in *Il Giornale del Genio Civile* (Galli et al. 1954), was an early recognition of Galli's knowledge of pre-stressed concrete technology.

Despite his early death, Galli's approach to construction continued to live on in the work of his student. It is no coincidence that Elio Giangreco's tubular bridge for the hydroelectric plant over the Tara, Puglia (1955), evoked the forms of the aqueduct designed by his master Adriano Galli.

5 DEDICATION AND AKNOWLEDGEMENTS

The paper is dedicated to the 42 workers who died in the accident of Cannavinelle and to Luigi Grieco (1920–2008). He worked as carpenter on the construction of the plant linked to the aqueduct. On the day of the tragedy, he got off duty just a few hours before the explosion.

The authors owe a special thanks to Marzia Marandola for her useful suggestions; to Andrea Fontaine and to the Comune di Mignano Monte Lungo for their precious archive materials; and to Paolo De Luce of Archivio Storico Enel (Figures 11–13).


Figure 13. View of the bridge in 2014 (source: the authors).

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History of Construction Cultures – Mascarenhas-Mateus & Paula Pires (eds)

Italian tall buildings by Società Generale Immobiliare (SGI) in the 1950s–1960s: Some Milanese case studies

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ABSTRACT: The paper presents the activity of Società Generale Immobiliare (SGI) in the 1950s and 1960s, focusing on tall building construction. This study enables the selected case studies to be related to the evolution of the national construction processes. This paper analyses the methods and process innovations of SGI, with reference to Milanese tall buildings, comparing them with other similar buildings in Genoa and Palermo. In Milan, SGI built the Velasca, Galfa, Porta Romana, Fara and Filzi towers (1956–63) and other tall buildings in residential complexes. This study explores how the company's Milanese projects impacted the construction of the Cantore and Park Riviera towers in Genoa (1963–69), and the Sperlinga Tower (1968) in Palermo. This paper aims to provide an overall vision of SGI's activity, taking into account studies done to date on selected major works. It is based on original archival sources, magazines and publications published by the company.

1 INTRODUCTION

SGI was founded in Turin in 1862, during the second industrial revolution, when Italy implemented two important programmes: a national railway network (following Unification in 1861) and reclamation of some districts that lacked minimum hygiene and habitability requirements in large cities (Giannini 2003).

SGI was one of the largest Italian General contractor companies which operated for more than a century (until 1988) in a variety of construction fields; the history of the company can be divided into four periods (Martini 2003). This study refers to the Ph.D. research project carried out by the author, related to the company's so-called "third period" (1950s–1970s) in Italy. It focuses on some tall buildings built by SGI in Milan, Palermo and Genova, from the mid-1950s to the early-1960s.

There is evidence that studies on specific buildings constitute tools to contribute to an organic reconstruction of the vast activity of SGI (Spina 2020). This paper focuses on a specific type of construction: tall buildings. It highlights the evolution of Italian industrialised construction techniques, considering SGI's achievements as exemplary.

The author focuses on Milanese buildings due to SGI's general approach to entrepreneurial activity. In Rome, since the early 1950s, SGI had large areas far from the city centre to create large suburbs; differently, in Milan, SGI bought areas gradually to construct buildings or complexes (Bonomo 2006).

Moreover, a cultured, theoretical debate about Triennale exhibitions (Expo) and the polytechnic universities was revived in Milan after the Second World War. These circumstances allowed for experiments in construction fields (specially in industrialization) thanks to which the symbolic buildings of Italian construction history of the second half of 1900s were created in Milan; SGI realised some of these, therefore, they will be analysed in this study.

Due to the holding role played by SGI, it is possible to analyse the entire building process that characterised its buildings. The SGI archive shows a recurring feature: SGI founded a *società controllata* (subsidiary company) for many real estate enterprises (Puzzuoli 2003). Moreover, SGI contracted most of its activities in Italy and abroad to Sogene (its subsidiary construction company) (Costantino 2003). SGI then contracted the design of major buildings to outside professionals not belonging to the technical office of the company. From the review of the buildings mentioned in the paper, evidence of both conditions emerges.

2 NOTES ON MILAN IN THE 1950S

In the post-World War II period, housing was a profound theme throughout Italy. Reconstruction was intended not only as war damage restoration but also as an opportunity to solve problems that had already existed prior to the conflict: crumbling houses, absence of basic health and hygiene requirements and overcrowding (Talanti 1981). In 1947, Piero Bottoni (1903–73) was the manager of the 8th Milan Triennale: the theme of the exhibition was "housing", supported by the start of construction of "QT8", a "model neighbourhood" within which modern housing design was to be experimented.

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The architectural debate that arose from Triennale exhibitions recognised Milan as an innovative city, within which it was possible to experiment with tall buildings. This type of construction refers to the American tradition born in the late 1800s, having roots in neither Italian nor European construction history and would thus be executed according to national craftsmanship methods (Cottone 2009). During the post-World War II period, tall buildings became a symbol of *modernity*, particularly appreciated by the Milanese managerial class who saw it as representative of a new *modern* horizon.

Milan was a symbolic city for architectural renovation: urban voids resulting from the war presented opportunities for experimentation (Irace 2004). This was in contrast to Turin, where a conservative attitude in architecture was clear, referable to the urban middle class and their reluctance to embrace change (Scrivano 2004).

In the post-war period, the *casa-albergo* in Via Corridoni was one of the Milanese buildings that marked the architectural history of the city (Lucente & Greco 2018); it was built between 1946 and 1951 on a design by Luigi Moretti (1906–73). He imported this type of building, consisting of apartments for one or two people with shared facilities, from northern Europe.

The Breda Tower is another symbolic Milanese building in Piazza Repubblica, 31-floors high, built between 1950 and 1955 on a design by architects Eugenio (1906–93) and Ermenegildo Soncini (1918–2013) and Luigi Mattioni (1914–61).

However, the most significant Milanese tall buildings are the Velasca Tower (1955–57) and the Pirelli Tower (1956–61). While being contemporary, the two buildings are expressions of the two different approaches that characterised Italian architecture in the post-war period. Architect Giò Ponti (1891–1979) designed Pirelli Tower in partnership with engineer Pier Luigi Nervi (1891–1979). G. Ponti was a supporter of a new architecture: the strong volumetric articulation provided by the lateral walls of the building is almost cancelled by the endless vertical cut on lateral fronts and on the part of façade consisting of a curtain wall. Architect Ernesto Nathan Rogers (1909–69) was the designer of Velasca Tower in partnership with architects Lodovico Barbiano di Belgiojoso (1909–2004), Enrico Peressutti (1908–76), Gian Luigi Banfi (1910–45) and engineer Arturo Danusso (1880–1968). He was a supporter of continuity with tradition, so much so as to define the building as the “Gothic Tower” of Milan (Tafuri 1982). It is identifiable as a strongly masonry volume. The walls are protagonists despite the vertical façade appearance given by pilasters and pillars; the curtain walls do not on the whole contribute to lighten the building.

The Galfa Tower (1956–59) is the closest building to Modern Movement principles, designed by Melchiorre Bega (1898–1976). Levity is its main architectural feature, thanks to an almost exclusive use of a glazed curtain wall. The shell of the building is close to that of the American tradition, referring to International Style (Mornati 2012a), differing from the Pirelli and Velasca towers in which continuous façades are not an undefined shell, but rather are placed between structural vertical lines, which mark the volume. This condition is a recurring character in the buildings analysed in this paper.

The listed buildings are some of the most significant constructions built in the cultured Milanese context of the 1950s. This paper focuses on tall buildings constructed by SGI in Milan in the 1950s and 1960s; the aim is to identify influences on the company’s tall buildings in Genoa and Palermo.

3 CONSTRUCTION TECHNOLOGIES IN MILANESE BUILDINGS

In the 1950s, in Milan, the skyscraper was both a symbol of Modern and a “single piece” or “landmark” in the evolving city skyline, designed for a hopeful post-war period. This ideological approach was consistent with the Italian construction tradition (Cottone 2009).

The 1930s had been a hopeful period for Italian construction: although the fundamental points of the Modern Movement had not taken root in the country, the reinforced concrete frame was introduced into masonry construction. This generated a (typically Italian) hybrid construction, compatible with basic skilled workers and with no support of good industrialization of the building sector (Iori 2012). Production of components for prefabricated brick slabs (to be completed on site) was the most significant industrial production in the building sector.

In the 1950s, construction methods were consistent with the described conditions. However, there was no doubt about important evolutions in construction techniques. Studying construction companies and built heritage are valuable investigation tools.

SGI had a primary role in the “new” Milan of the 1950s: the subsidiary company, Sogene, built the Velasca and Galfa towers. The Velasca Tower is one of the most significant case studies for rationalization and mechanization of the construction site. The building, built with a reinforced concrete structure, included 29 floors, two of which are underground, for a total height of 87.50 m, excluding the technical spaces (Pifferi 1959). SGI adopted innovative technical solutions for such arduous building in site management, consisting of industrialised frameworks for variable-section pillars and sandwich panels for façades (Spada 2020). The tower (built in only 20 months, from February 1956 to October 1957) introduced numerous innovative construction solutions with the aim of creating an iconic building, therefore there were no “serial” methods which could be reused without first making changes.

Therefore, the Velasca Tower underlines a fundamental condition in Italian construction history of the 20th century: SGI planned its own resources to respond to “market demand of modernity”, without failing the craftsmanship that had characterised building

Figure 1. Filzi and Fara towers model. Source: ACS, SGI collection, folder 4803–1, Realizzazioni 1959.

Figure 2. Filzi and Fara towers site. Source: ACS, SGI collection, folder 4803–1, Realizzazioni 1960.

production in the 1930s and that would continue to characterise courtly constructions in the 1950s and 1960s (Poretti 2004). SGI's approach to great works distinguished the building production of the company: in parallel to national practise, it used industrialised methodologies blended with craftsmanship practices.

Still in Milan, in the business centre between Via Fara and Via Filzi, SGI realised two 18-storey tall buildings (60 m), between 1959 and 1960 (Ed. 1959–61) (Figures 1 and 2). The Filzi Tower was designed by architect Alziro Bergonzo (1906–97) with 28 prestigious flats on the upper floors, ten offices on the lower floors, as well as shops and garages. The Fara Tower was designed by architect Luigi Mattioni as a *casa-albergo*: it had comfortable, small, fully-furnished flats (the interior designer was architect Angelo Ostuni), equipped with air conditioning. SGI embraced the *casa-albergo* design theme that was such a popular housing solution in the city, able to give a rational solution for long-term accommodation as well.

The two tower façades are highlighted by vertical lines given by the structure in the foreground and the curtain wall in the background. The infill panels of the Fara Tower are made by a sandwich layer under the windows and fixtures large enough to fit in vertical panel supports; therefore, building shell assembly was faster than with traditional construction. The Filzi Tower rear prospect is the same; in the front one there is an entirely glazed curtain wall, still characterised by the vertical lines that contribute to streamline the two buildings. They are identified as "towers", but the longitudinal dimension plan prevails over the transversal one, as is typical of "linear" buildings. The Filzi and Fara towers are architecturally and technologically less complex buildings than the Velasca Tower. They are notable constructions but not iconic constructions with particular connotations (like the Velasca Tower) such as to establish them among the landmarks of Italian construction and architectural history of the 20th century. The Fara and Filzi towers have reinforced concrete frames, appearing on the façades according to described solutions, but appearing less prominent and more cautious than the Velasca Tower. The common master element is the use of a curtain wall, in order to obtain a quick assembly of the building envelope and to facilitate maintenance operation (particularly difficult in such tall buildings).

It is interesting to note that the Filzi and Fara towers were commissioned by *Immobiliare Centro Uffici* (an SGI subsidiary company) and built by *Impresa Eugenio Grasseto* (Ed. 1959–61). This is a condition that attests SGI's interest in real estate business management: building production is not only managed by the company (though it holds the *Regia tecnica*) but also by third-party companies in charge of the realization (Sogene is the master but not the sole construction company working for SGI).

As mentioned in the introduction, the theme of subsidiary companies is noticeable in other SGI realizations, for example in the Domus Omnium complex that should have been built in Piazza Loreto in Milan, commissioned by *Alberghi Ambrosiani S.p.A.* (an SGI subsidiary company) (Ed. 1963–65). It is an unbuilt project by architect M. Bega (designed since 1963) due to a failure of obtaining building permits (Greco 2012). The prestigious complex would have consisted of offices, shops, exhibition halls, hotel and residential solutions. Looking at the design model photos (Figure 3), a 22-storey tower should have been the centrepiece of the complex; it was designed as a

Figure 3. Domus Omnium model. Source: ACS, SGI collection, folder 4803–1, Realizzazioni 1965.

glass parallelepiped, rising from the basement volume. Thus, the building shell is dematerialised, ethereal; this is not for strictly architectural reasons, but rather to approach the industrial design object ideal.

The level of Italian industrialization in fixture production was more advanced than in curtain wall production. The Domus Omnium construction probably would have been faster than the Velasca one, in which the artisanal curtain walls were prefabricated on-site in order to "preserve" Italian craftsmanship manners to create specific a singular building (not responding to industrial production logic) (Poretti 2009). The theoretical tall building construction approach for *Domus Omnium* was actually used by M. Bega (consequently by SGI) in the Galfa Tower, another symbolic Milanese building in the 1950s.

It was built by *Sogene*, between 1956 and 1959, facing the Pirelli Tower which was being built simultaneously (Mornati 2012b). The almost exclusive use of totally glazed façade panels for the Galfa Tower was characteristic in M. Bega's architectural approach, due to the American construction approach to tall buildings. This is an important difference from the Pirelli Tower in which the curtain wall is fixed between heavy concrete shells. However, the Galfa, Pirelli and Galfa towers attest Milanese experiments in the 1950s (two of which by SGI); although different from each other, equally they are taken as part of Italian construction history of the second half of 1900s.

SGI also experimented with including tall building in "ordinary" housing complexes. In the early 1950s, the company built many wide residential complexes in Milan (Bonomo 2006); moreover, in the post-war period, SGI participated in the theoretical debate on building industrialization through the construction of some buildings in the QT8 experimental district (Ed. 1956–58).

Figure 4. Towers of the Monti-Pagano district under construction. Source: ACS, SGI collection, folder 4091–265, Photographic archive.

Figure 5. Towers of the Monti-Pagano district. Source: ACS, SGI collection, folder 4091–265, Photographic archive.

Later, at the end of the 1950s, a new question arose in some elegant residential complexes: SGI designed one or more towers between linear buildings, like a distinctive element. It is the case of the Monti-Pagano district (Figures 4 and 5), built between 1958 and 1961 in a 20,000 square-metre area between Via Pagano and Via Monti. It was enhanced by a common garden also equipped with a swimming pool.

The architect, L. Mattioni, was the project manager of the area and designer of two 60-metre towers within

Figure 6. Tower of the Centro Romana district. Source: ACS, SGI collection, folder 4091–105, Photographic archive.

which there are two large and elegant apartments on each floor. Moreover, in the district there are two 9-storey linear buildings and one 7-storey linear building designed by the SGI technical office (Ed. 1958–61).

This is a good case study to highlight a recurring condition in some SGI residential complexes: the most valuable building was designed by a noted professional (freelance, not included in the organizational chart) in order to reward the entire complex, while the other ordinary buildings are designed "in-house" by the company's technical office. SGI holds the *Regia Tecnica* (construction supervision) in order to guarantee the success of the investment also through the construction contract entrusted to the subsidiary, *Sogene*. Referring to the prestigious and long-time collaboration with architect L. Mattioni, he designed the Fara Tower, the Monti-Pagano Towers and worked with architect M. Bega for the Domus Omnium in Piazza Loreto. It should be noted that architect Angelo Ostuni was the interior designer of the Fara Tower and the Monti-Pagano Tower hall; he was probably Mattioni's partner during the construction of the aforementioned buildings.

The Centro Romana district in Milan (Figure 6) was also the result of SGI's prestigious collaboration with professionals: architect Paolo Chiolini designed the area masterplan and a 24-storey tower (81 m). Construction took place between 1959 and 1967, revising the number of buildings and the layout several times. The complex currently consists of eight linear buildings (in addition to the tower) designed by SGI's internal technical office. *Società Immobiliare Fleo* (an SGI subsidiary) is the holding company which ordered the realization; Sogene was the construction company engaged (Ed. 1959–67).

Figure 7. Centro Romana district site tower: in the foreground, the hollow floor blocks before casting concrete slab. Source: ACS, SGI collection, folder 4091–105, Photographic archive.

Figure 8. Tower of the Centro Romana district: façade detail. Source: ACS, SGI collection, folder 4091–105, Photographic archive.

Photos of the Centro Romana construction site (Figure 7) show only one industrialised element for the bearing structure: the hollow floor blocks, according to national construction trends. The tower shell was marked by vertical structural elements that invoke the Fara Tower's architectural design. Also in this case, the continuous vertical supports were useful for attachment of the fixtures; the panels under the windows were used for the air conditioning cabinet, above the windows there were roller-shutter boxes (Figure 8). The partitions consisting of a matt panel, window and roller-shutter boxes were separated horizontally from each other by the floor slab. Façades were covered by tiles to reduce maintenance time compared to plastered surfaces. This was a recurring solution in Milan: the buildings in the Monti-Pagano district also have façades covered by clinker, stone and ceramic tiles.

According to reasoning for the Monti-Pagano district, the Centro Romana district is equally identified in the Milanese landscape by a tall building: it is a useful landmark in identifying the area. Therefore, tall buildings stand out from residential complexes. They are an architectural "quality index" for residential complexes built between the late 1950s and the early 1960s. They are landmarks in the post-war Milanese skyline, next to the iconic buildings listed in the first part of this paper.

Figure 9. Tower of the Residence Park Riviera. Source: ACS, SGI collection, folder 4091–265, Photographic archive.

4 INFLUENCE OF THE MILANESE REALIZATIONS ON BUILDINGS IN GENOA AND PALERMO

SGI built tall buildings in some other Italian cities, although less consistently than Milan; Genoa is one of them.

In the early 1960s, the design of Residence Park Riviera (in Quarto district, between Genoa city and Nervi) (Figure 9) evoked the Milanese residential complex. The complex consists of five linear buildings designed by SGI's technical office and an 18-storey tall building as the landmark, designed by architect Luigi Carlo Daneri (1900–72) (Ed. 1961–70). On the main fronts, the tower shell is on two layers: there are wide balconies covering full glazed fixtures while other façades are marked by structural vertical and horizontal floor lines, so as to support the infills.

The Cantore Tower is another interesting construction, located in the Genoa harbour; it is a 22-storey tower with multiple uses (an 8-storey building is located next to it): housing, *casa-albergo*, offices and a shopping centre. It is located in Sampierdarena district, next to the highway, closer to the city centre: the Cantore Tower is part of the new constructions for the harbour headquarters (Ed. 1964–70). The tower was designed by architect Renzo Del Debbio, and was built by Sogene between 1967 and 1970, following the large works in Milan; it was an expression of SGI's know-how in the construction of tall buildings (Figures 10 and 11). Similarly to the towers mentioned, the Cantore Tower has vertically divided façades in order to assemble the infill panels. This is an artifice used only for the tower: in fact, the 8-storey building next to it has traditional façades characterised by a simple, masonry wall interrupted by the empty window spaces (Figure 12).

Palermo is another Italian city where experiments in tall buildings took place in the 1950s and 1960s. During the post-war period, reconstruction was driven

Figure 10. Cantore Tower site. Source: ACS, SGI collection, folder 4091–88, Photographic archive.

Figure 11. Cantore Tower site. Source: ACS, SGI collection, folder 4091–88, Photographic archive.

Figure 12. Cantore Tower façade. Source: ACS, SGI collection, folder 4091–88, Photographic archive.

Figure 13. Sperlinga Tower under construction. Source: ACS, SGI collection, folder 4091–148, Photographic archive.

Figure 14. Sperlinga Tower. Source: ACS, SGI collection, folder 4091–148, Photographic archive.

by design competitions in order to provide urban renovation of some districts and to collocate new "landmarks" in the city: the 13-storey twin towers near the city harbour and the 32-storey government building are two examples of this urban design. Differing from the Milanese experience, in Palermo the corporate organization was inadequate to support complex building construction and there were not experienced local professionals like those in Milan who had studied at the Politecnico. Therefore, in Palermo, an integrated architectural, structural and plant design was not as widespread as it was in Milan. It was customary to arrange the loadbearing structures in pre-arranged architectural models (Cottone 2009).

Despite their know-how, even SGI seems to have "succumbed" to this "southern"' approach to the construction of tall buildings: between 1963 and 1970, SGI built the Villa Sperlinga residential complex in which the 17-storey Sperlinga Tower (60 m) is the "landmark" designed by architect Gabor Acs (1926-) (Ed. 1961–72). He was a permanent SGI collaborator for foreign realizations; the Sperlinga Tower is the only building designed by him for SGI in Italy (Lecoque 2017).

According to Antonio Cottone's studies on tall buildings in Palermo, the site construction photos (Figures 13 and 14) show a reinforced concrete frame structure with traditional hollow block infill; no curtain walls are used.

5 CONCLUSIONS

The case studies chosen for this paper highlight two important issues: the strong will to experiment in the construction field in Italy between the late 1950s and early 1960s (before business in the construction sector moved to foreign, heavy prefabrication systems useful to satisfy the strong housing demand), as well as the opportunity to refer so many buildings to a single holding and construction company (SGI).

During the period analysed, SGI had already been active for over half a century in all fields of construction and civil engineering. Despite this, it participated in new business challenges deriving from new demands of the real estate sector. Surely this was possible thanks to an open-minded company management.

The organization of the process that SGI set in motion for each realization highlights the robust structure of the Company: having a subsidiary construction company guaranteed timing regularity and expense control. Collaborations with influential professionals (supported by the Company's internal technical office) ensured accurate design and architectural quality.

Compared to Italian building industrialization levels, SGI echoed the national trend of the late-1950s: it preserved the (always different) relationship between projects and specific architecture, or rather "craftsmanship", in its construction approach. However, compared to Italian construction in the 1930s, new facilities were available: new industrialised products were used on construction sites, in order to speed up and rationalise the construction process. The curtain wall constituted a recurring technical element in the listed case studies. Therefore, it was used both for rationalization and to speed up façade construction, although it was individually designed for each building.

Studies carried out and in progress on SGI (including degree and doctoral theses) demonstrate the expanse of SGI's domain, so it still has to be fully structured. According to the author's ongoing studies, this paper focuses on technological aspects related to the evolution of the degree of SGI's industrialization, following the national trend. Starting from some iconic SGI buildings like the Velasca and Galfa towers, this study focused on other less-known buildings by the company which are useful in highlighting essential aspects of the company's approach to tall buildings, as an experimentation field for building industrialization.

From the analysis of these constructions, it is possible to note that there are different degrees of industrialization (coexisting in the same construction company) in coeval buildings. The Velasca and Galfa towers show rationalised procedures for almost the entire construction; they began the SGI tower-building production in Milan. For the subsequent Milanese and Genoese towers, industrialization techniques are notable on the building shell, which used curtain walls. Traditional – never dismissed – construction techniques are remarkable in the Cantore Tower in Palermo, although it is the last in chronological order.

Therefore, it could be claimed that SGI is a "mirror" of the Italian history of industrialization. Through its achievements, it is a notable case study to understand both the coexistence and mixture of rationalised and traditional techniques, between the 1950s and 1960s.

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History of Construction Cultures – Mascarenhas-Mateus & Paula Pires (eds)

Construction culture between tradition and modernity: Three works by Álvaro Siza

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ABSTRACT: Between 1958 and 1966, Álvaro Siza designed three remarkable works in Leça da Palmeira: Boa Nova Tea House (1958–63), the swimming pool at Quinta da Conceição (1958–66) and the ocean swimming pool (1959–66; building completed in 1973). Even though these buildings were designed within a short space of time and were built in the same area, they reflect the evolution of the construction culture in Portugal. During the 1950s and 1960s, construction in Portugal evolved from predominant recourse to traditional technologies using pre-industrial materials (often taking the form of a hybrid combination with modern solutions) towards the gradual affirmation of modern construction features made possible by the advances in the construction industry (mainly reinforced concrete). This paper explores the evolution.

1 INTRODUCTION

Between 1958 and 1966, Álvaro Siza Vieira designed three important works in Leça da Palmeira, near Porto, in the north of Portugal: Boa Nova Tea House (1958–63), the swimming pool at Quinta da Conceição (1958–66) and the ocean swimming pool (1959–66). Although these projects were built in the same area and designed almost simultaneously, their construction features are quite different: in Quinta da Conceição and in the Tea House, Siza used a mixture of traditional and modern materials (stone walls, pitched concrete slabs covered with tiled roofs), attempting to combine vernacular constructive elements with the use of modern technologies; in the ocean swimming pool, however, Siza adopted an abstract neoplastic language and made a concerted use of modern technology (walls in reinforced exposed concrete).

This shift can be explained by the evolution of the construction culture and processes taking place within Portugal during the 1960s (in keeping with the evolution of the international debate), with Siza's work gradually amounting to a reaction to the formalist and regionalist trends arising from the "Survey on Popular Architecture in Portugal" (1955–61).

This paper will present a comparative analysis of the construction features of the three works, with greater detail being provided on the ocean swimming pool. Hence, the roles of the different actors involved in the building process (architects, engineers, contractors) are examined, as well as the materials and building technologies used, viewed in relation to the construction culture of this period, between tradition and modernity.

The methodology of this paper is based on oral sources (interviews with building actors), as well as the analysis and interpretation of documentation obtained from several public and private archives, such as drawings, administrative documents, manuals, notes, photographs, budget estimates, site calendars and academic works.

The large amount of sources available allowed for a more detailed analysis in the case of the ocean swimming pool, namely in relation to: i) the planning of the building site (staff, office and facilities for workers, chronogram), ii) the transport and manufacture of materials (crane, carpentry of the formwork, steel reinforcement, concrete mixer) and iii) the construction processes: demolitions, excavations made in the earth, sand and rock; hydraulic masonry foundations; landfills; reinforced concrete walls and roof slabs; loose stone drainage on the back of the retaining walls; waterproofing screens in the roofs; cyclopean concrete in the external pavements; flooring with concrete slabs; water supply devices, sanitary installations and infrastructure.

2 THE PORTUGUESE CONTEXT: BETWEEN TRADITION AND MODERNITY

Between 1933 and 1974, Portugal was governed by the *Estado Novo* ("New State"), the dictatorial regime of António Salazar, which sought to impose a romantic vision of vernacular values on Portuguese architecture, combined with an imperial monumentality influenced by Nazi Germany and Fascist Italy (Fernandes & Pereira 2019).

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However, with the gradual affirmation of a new generation of building actors with international influences, pressure from the State decreased, and the imposition of official languages was restricted to certain types of public buildings (such as courthouses); in private buildings, the modern style and construction solutions (directly influenced by Le Corbusier) dominated everyday production (Fernandes 2016).

The year 1955 marked the beginning of fieldwork for the Surveys on Portuguese Vernacular Architecture, a State-funded programme promoted by the Union of Portuguese Architects. If this was a final attempt by Salazar to create a "Portuguese style" (as an alternative to modernism) in the work of architects, it failed: the Surveys proved that there was not just one single construction culture that was recognizable throughout the country (on the contrary, there were several regional variations) and demonstrated the compatibility between the vernacular legacy, modern values and construction features.

Hence, between 1955 and 1961 (during the survey on *Popular Architecture in Portugal*), a new Portuguese Architecture was born, in which traditional technologies (stone walls, timberwork, pitched roofs covered with ceramic tiles) were progressively combined with modern features such as reinforced concrete structures: the municipal market of Vila da Feira (1954–9), the Ofír House (1957–8), the tennis pavilion of Quinta da Conceição (1956–9) and the Cedro Elementary School (1957–61), all designed by Távora, and the swimming pool of Quinta da Conceição (1958–66) and Boa Nova Tea House (1958–63), both initiated in Távora's office and later developed by Siza alone.

The popularity of the book *Popular Architecture in Portugal* (Amaral et al. 1961), created a regionalist trend in Portugal, as the reinterpretation of vernacular forms and construction characters proved to be in tune with the modernist principles of functionality and the honest use of materials. However, during the 1960s, it became clear that this vernacular influence was crystallizing "a reality that was, in fact, rapidly disappearing and could not express the contemporary times" (Fernandes 2016, 403–4).

This context explains the construction shift that can be detected when comparing the works by Siza that are presented in this paper: in other words, contrasting the swimming pool of Quinta da Conceição and the Boa Nova Tea House with the ocean swimming pool of Leça da Palmeira.

3 THREE WORKS BY ALVARO SIZA

These three works were part of a plan for the promotion of tourism in the village of Leça da Palmeira, envisaged by the Mayor Fernando Pinto de Oliveira (1911–75), and were built between 1958 and 1973, at an early stage in Siza's career.

3.1 *Boa Nova restaurant and tea house (1958–63)*

In Boa Nova, there is a carefully established dialogue between the Tea House, the pre-existing rocks, and the nearby chapel; furthermore, the exterior and interior promenades have a constant correlation with the sea view (Ferreira & Fernandes 2021, in press).

Initially designed at the studio of Fernando Távora for presentation in a public contest (won in 1956), the subsequent commission and its corresponding authorship were later entrusted by the master to Álvaro Siza, a collaborator in his office between 1955 and 1958.

The engineer for this project was Aires Pereira and the contractor was Soares da Costa, SA, a firm dedicated to the execution of high-quality workmanship, which, during the 1960s, expanded its activity in the Portuguese territory and, in the 1980s, began its international expansion. At the end of the 20th century, it was one of the largest contractors in the country.

Following the lessons that he had learned from Távora, Siza proposed the use of a mixture of traditional construction culture (timber joinery and ceilings, stone walls, and ceramic tiles) and modern construction technology (pitched concrete slabs, reinforced concrete walls and pillars).

The building has sloping pitched roofs of brick slabs with a main structure of reinforced concrete beams, supporting a covering of Roman roof tiles, laid with a mortar made from cement, sand and water repellent. To fix the tiles in place, concrete slats were added to the slabs, with small openings to prevent water from accumulating in the event of rainwater infiltration. The roofs' gutters and flashings are made of copper.

While the entrance floor is supported by a reinforced concrete slab, the whole ground floor is laid upon waterproofed concrete walls and foundations.

The reinforced concrete exterior walls and the basement are directly supported by the rocks or by cyclopean concrete walls.

In contrast, the inner walls in perpend stone of 28 cm or brick of 15 cm are directly supported by a reinforced concrete foundation, while the rest of the building, also made of brick (8, 5 and 3 cm), is laid directly on the floor screed. In the western façade, the reinforced concrete pillars have a foundation made of the same material.

Apart from the building's foundations and pillars, all the walls are plastered and painted white.

Most of the wooden elements are built in afzelia wood, used in the ceilings, the interior flooring and in all the frames, including a set of sliding windows (Figures 1–6).

3.2 *Quinta da Conceição swimming pool (1958–66)*

The swimming pool is implanted on an uphill path that passes through Quinta da Conceição, a public park designed by Távora (1956–60) in the grounds of an old convent (of which there were almost no traces).

Figure 1. Boa Nova Tea House and Restaurant, concrete foundations, 1959 (Câmara Municipal de Matosinhos).

Figure 2. Boa Nova Tea House and Restaurant, 1963 (Câmara Municipal de Matosinhos).

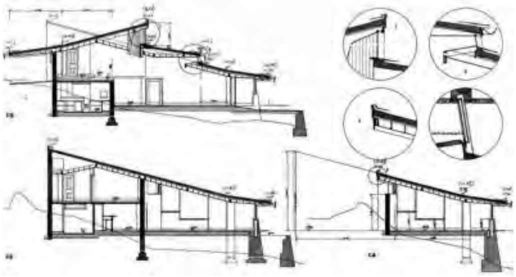

Figure 3. Boa Nova Tea House and Restaurant, A. Siza, cross sections and details, 1959 (Câmara Municipal de Matosinhos).

Figure 4. Quinta da Conceição swimming pool, changing rooms 1965 (Trigueiros 1997, 43).

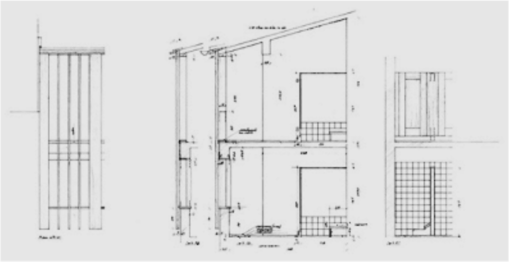

Figure 5. Quinta da Conceição Swimming Pool, A. Siza, cross sections 1961 (Arquivo da Fundação Serralves).

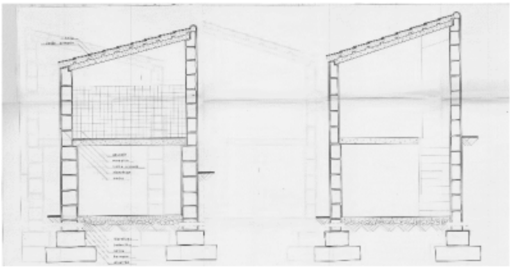

Figure 6. Cross section of the changing rooms, Student Works 1991/1992 (Centro de Documentação da FAUP).

For this construction, the engineer was Asdrúbal Teixeira Varejão and the contractor was a local firm, Domingos Soares Lopes.

In this project, Siza once again used a combination of traditional construction culture (masonry walls, timber, and ceramic tiles) and modern tectonics (reinforced concrete slabs and external walls).

The retaining walls and foundations of the buildings that house the bar and changing rooms are made with perpend stone. The walls are sealed with granite masonry and the pool's walls are made of masonry with a concrete filling. The retaining walls of the southern area and of the technical areas on the lower floor are, however, built in cyclopean concrete.

All the slabs are made of reinforced concrete, except the ground floor of the bar and changing rooms. The roof slabs are covered with Roman tiles. The eaves and joinery are made of iroko wood.

Apart from the areas covered with turf and trees, all the outside flooring was made of cement screed, while the concrete slabs are covered with plastic paint in the changing rooms and bathrooms, and ceramic tiles in the bar.

Built over the pre-existing water tank, the bottom of the swimming pool is made of concrete slabs, while the walls are made of masonry filled with concrete. All the joints were filled with hot plastic, while the walls were covered with mortar and painted.

3.3 *Ocean swimming pool (1959–73)*

In 1960, Siza began to design a second pool on the seafront of Leça da Palmeira, near the Tea House. The

Figure 7. Ocean swimming pool, construction of the southern area (Mota, 1872; Centro de Documentação da FAUP).

design of the 20 × 33-metre tank was commissioned from Bernardo Ferrão (Fernando Távora's brother) by Matosinhos Municipal Council. However, given the delicate nature of the landscape, he recommended Álvaro Siza to design the pool and the buildings.

The project has undergone several revisions over time; it opened to the public in 1965, but the building we find there today was only completed in 1970–3 when the 45° wall was built, protecting the bar from the north wind (Ganshirt 2004). Siza proposed that the building should be anchored "like a boat, to the marginal wall", relating the gentle slope of the roofs to the three parallel lines visible at the site (Siza 1980, 23–4).

Here, just as in the Quinta da Conceição pool and in the Tea House, the architecture can only be fully appreciated from the promenade, where the building appeals to all human senses. However, in the ocean pool, such an effect is achieved through the different constructive options that were taken: the exposed concrete walls are shown in their rough natural state, still displaying the marks of the formwork. Despite the limited use of cement and their limited reinforcement, these walls have gained a great binding over time and present a grey tone that is in perfect harmony with the pre-existing rocks and sand.

The gently sloping copper covering of the changing rooms displays a modern approach to an ancient system: it is supported by beams made of riga wood (recycled from demolished constructions), darkened by the burnt oil used in its treatment. The height of these roofs allows the creation of transversal natural ventilation between the roof and the walls. Also, all the changing rooms' partition walls and most of the doors are also made of wood, which are either suspended on the roof or raised from the floor to allow easy washing of the pavement (Figures 7–9).

4 OCEAN SWIMMING POOLS. TOWARDS A MODERN CONSTRUCTION SITE

The large amount of documentation available about the ocean swimming pool (written, graphic and photographical) and oral sources (interviews with Arch. Alvaro Siza and Eng. António Ferrão, son and former collaborator of Bernardo Ferrão who was the engineer and contractor), made it possible, even over half a century later, to re-establish the history of a building site from the 1960s–1970s.

Figure 8. Ocean swimming pool, building housing the changing rooms 1965 (Arquivo Câmara Municipal de Matosinhos).

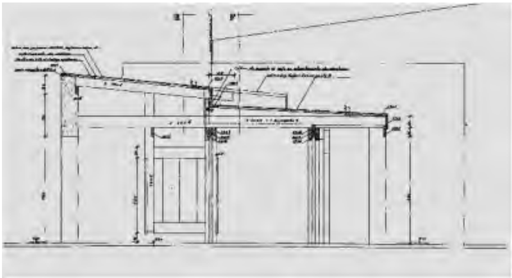

Figure 9. Ocean swimming pool, A. Siza, cross section showing wooden structure and copper covering, 1965 (Arquivo Câmara Municipal de Matosinhos).

Hence, we can reconstruct the building site from the documents kept in the archives of Matosinhos Municipal Council (drawings, epoch photographs, project descriptions, budget estimates, chronograms, etc.), and in the Archives of the Faculty of Architecture of the University of Porto, through a report compiled, during his internship period, by a student of Architecture at the Porto School of Fine Arts. This report relates in particular to the third phase, which involved the extension of the buildings (Mota 1972).

4.1 *Building actors*

Construction of the ocean swimming pool was programmed in four phases: in the first and second phases (1960–6), the contractor was a small local firm, Ribeiro da Silva, Lda. (later purchased by a larger company, Mota Engil, Lda.), owned by the engineer Bernardo Ferrão (1913–82), who designed all the building's structures and infrastructure; the third and fourth phases (1965–73) were the work of the firm Enobra SARL (Mota 1972), including a project that involved the creation of a restaurant over the rocks, which was never built.

In all the phases, the engineer was Bernardo Ferrão, who made several important contributions to construction history: on the one hand, through his experimental projects and built works (the Leça Movable Bridge, the Ribeira Tunnel, the retaining walls of the Douro riverside district, etc.), he was one of the first engineers in Portugal to use pre- and post-cast concrete (Oliveira 1983); on the other hand, as a prolific writer and editor, collecting information relating to the technical state of art (e.g. retaining walls and masonry coatings – Ferrão 1945), construction legislation and regulations (Ferrão 1944; 1962), safety and accidents at work (Ferrão 1962), contractors (Ferrão 1962) and the accounting of public works (Ferrão 1963), among other subjects.

Thus, due to his great expertise, Bernardo Ferrão played an important role, working both as an engineer and a contractor in the construction of this building, which was one of the first in the country to make use almost exclusively of exposed concrete.

4.2 *Building materials and techniques*

This building is constructed with few materials and techniques: assembled copper coverings, reinforced concrete, stone and wooden structures and joinery. The wooden elements are assembled with brass screws and coated with a varnish that was traditionally used in shipbuilding, to create a washable and waterproof surface.

As far as concrete and stone are concerned, Ferrão had performed previous research and practical works specifically focused on retaining walls. The swimming pool's buildings are anchored at the lower level of the seaside avenue. In this way, all the east side walls are retaining walls (Figure 10) composed of two layers: i) an outer one made of reinforced exposed concrete and ii) an inner one in cyclopean concrete.

The back of the latter has a layer of loose stones, with a draining pipe at the bottom, which works as a water draining curtain. This highlights the use of hybrid solutions of traditional construction techniques combined with modern ones that Siza was employing in his works during this period of his career.

As regards the concrete used in the building site, we have different compositions: i) the cyclopean concrete walls were composed of stones, sourced from the site, filled with 300 kg cement plaster; ii) the foundation, the platform pavements and the bar's triangular terrace is made out of 75% concrete of 250 kg cement; iii) the simple concrete walls are reinforced with 10 kg of rebar per m3 in the retaining walls and 15 kg/m3 in the remaining walls; iv) the concrete roof slabs in the north and south roof gardens have 52 kg/m3 of rebar and 130 kg/m3 respectively; v) in the north area, the slab also has a concrete beam (which extends to the retaining wall shown in Figure 10) that is reinforced with 190 kg/m3.

4.3 *Construction site, staff, chronogram*

The staff facilities were located at the northern end of the construction site: the supervisor's office (6 m^2), the tool area (15 m^2), a dormitory (25 m^2); a kitchen with a small bathroom (9 m^2).

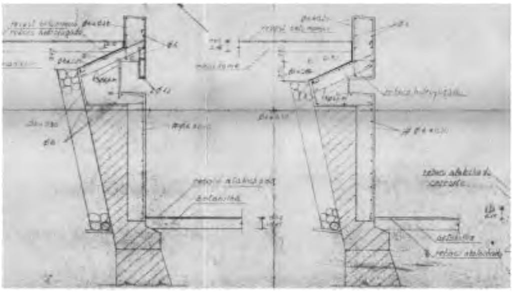

Figure 10. Ocean swimming pool, B. Ferrão, retaining walls, 1970 (Arquivo Câmara Municipal de Matosinhos).

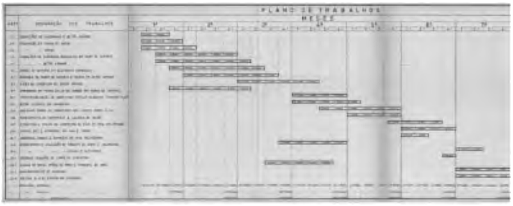

Figure 11. Ocean swimming pool, construction site chronogram (Mota, 1972; Centro de Documentação da FAUP).

The construction staff consisted of one civil engineer (the contract director), one builder (being the liaison between the contract director and the site foreman), one foreman, eight stonemasons, five carpenters, two builders and ten labourers.

The organisation and planning of the work were conducted by the technical office of the contractor's firm. The building site for the third phase was estimated to be in use for 210 days. The construction site chronogram was presented in the form of a GANTT bars type work plan (relating the works to be done with the weeks that were needed and the costs involved). The financial plan was based on a chart that included both the contractor's receipts and the contractor's payments (Figures 11, 12).

The building site included several areas for the manufacture and assembly of materials (steel reinforcement, formwork, masonry, among others). The area used for the assembly and cutting of steel was equipped with a folding table and manual cutting scissors. The amount of steel used in the third phase (7000 kg) did not require the use of more efficient electrical equipment. Similarly, the formwork area was simple, with only one circular saw.

Moreover, the site had two concrete mixers that were used to produce a total volume of concrete of 800 m^3: one BH 400 from the NOE firm, with a production capacity of 12 m^3/h; and one that was used for finishing work, with a lower hourly output. To move the materials, there was a crane (type L 16, from the NOE firm) and a dumper truck (of the Thwaits Orion type, with a capacity of 800 litres).

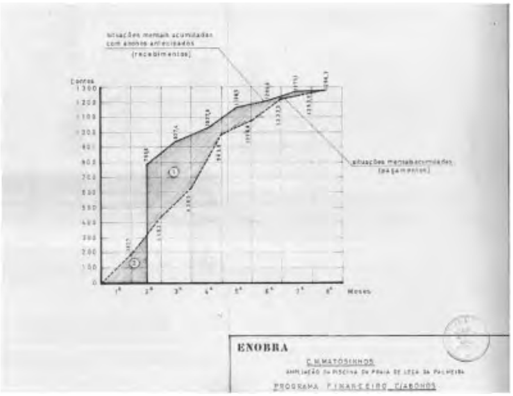

Figure 12. Ocean swimming pool, construction site financial chart (Mota 1972; Centro de Documentação da FAUP).

4.4 *Excavations, foundations, landfills*

After the demolition of the previous retaining walls, a bulldozer was used to excavate the earth, sand, and rock, with 1/3 of what was left being rock, while the remaining 2/3 consisted of earth. The rocks were broken up using explosives and were later reused for drainage purposes and for the hydraulic masonry walls and foundations (Figures 13–16).

The hydraulic masonry foundations were composed of rocks and mortar mixed with 300 kg of cement. The concrete foundations and their respective foundations were reinforced with steel and compacted by vibration.

Afterwards, the land was filled manually with 25 cm layers that were watered and beaten. The remaining debris was removed with a bulldozer and truck to a council refuse tip (2km from the site).

The drainage system on the back of the retaining walls was made with loose stone, manually arranged with a porous concrete pipe (10 cm in diameter).

4.5 *Retaining walls and concrete walls*

The retaining walls at the northern and southern ends of the site were built in cyclopean concrete, with the stones being manually arranged, cleaned and watered. A plaster made of cement and sand was applied to the back of the walls, with 0.588 litres of "Feb-proof" being used in the manufacture of each 50 kg of cement, making it water repellent and more compact.

The exposed concrete walls required a careful execution of the formwork in order to define the horizontal lines. The formwork was made of pinewood, which could later be reused due to its thickness (4 cm) and the application of oil. These walls are poorly reinforced, with a 5 mm-thick mesh, consisting of a grid of 15 × 15 cm.

Stretchers were affixed to the side walls of the formwork. The shoring was made using (15 cm) pine posts and foundations.

All the expansion joints were made of Meyco rubber instead of copper because the former material offered better resistance to the vibrator during concreting. The slabs were also separated from the walls to provide an improved structural behaviour.

Figure 13. Ocean swimming pool, building site, 1971 (Mota 1972; Centro de Documentação da FAUP).

4.6 *Concrete slabs*

The roof slabs were built without any interruption (to avoid joints) and the concrete was mechanically vibrated, using a Wacker machine.

The slabs were waterproofed with prefabricated plastic-asphalt screens (Morter-Plas), using a polyethylene film cover on both sides and special catalytic asphalt layers. These were applied directly on top of the regularization with fire-welded overlaps of 10 cm. These screens reached all the way to the roof plateau, with a double layer at the edges, where they were welded.

Moreover, a final protection was applied in the form of screed (1:3, cement and sand, with 3 cm and a spoon finish).

4.7 *Pavements*

All the exterior platforms and the southern ramp were made of cyclopean concrete, with 75% concrete (250 kg of cement) and 25% splinter. A mortar made of cement and sand (1:3) was applied on top.

The pavement in the north and south buildings received a water repellent and regulating screed with a plaster finish.

All the other exterior areas, the changing rooms and bathrooms have prefabricated slabs placed over a water repellent screed (4 cm thick), reinforced with mesh and executed with white cement.

4.8 *Water supply, services and infrastructure*

The water supply network was made with galvanised pipes when it was built-in, and with copper pipes when it was exposed (in the showers and in the water supply for the urinals), while the taps and dowels were made of copper-plated brass.

The water used in the swimming pools is treated with three clarifying filters, made of mild steel sheet, circulating in iron pipes with the help of two groups of electric pumps, made of phosphorous copper. The swimming pool's water system is made of fibre cement pipes.

Rain and residual water is drained through glazed stoneware pipes, using patio syphons and visit boxes, floor drain boxes and connection boxes with brass drain grates. The bathrooms use syphon toilets, washbasins and urinals from Valadares, shower tubs and foot basins.

This building site is an expressive example of the dichotomy that was prevalent in the construction culture of this period, with traditional features (hidden retaining walls made of loose stone and concrete, wooden scaffolding, manual cutting scissors) being combined with the use of modern equipment and technology (crane, concrete mixer, rubber joints).

5 CONCLUSIONS

The three buildings presented in this paper demonstrate how the use of different construction methods and materials led to the development of a new architectural language. With the construction of the ocean swimming pools, Siza affirms a construction culture transition that marked a turning point in his career and strongly influenced the subsequent production of other building actors. As mentioned earlier, this was the result of the evolution of the Portuguese construction culture and its accompanying debates in the 1950s and 1960s (together with the advances allowed by the industrialization of construction), leading to the affirmation of modern construction features, but also continuing to be linked to traditional building methods.

In the swimming pool of Quinta da Conceição and the Boa Nova Tea House, Siza used traditional materials (timber and ceramic tiles) and modern techniques (reinforced concrete), combining vernacular and modern systems (tiled roofs placed over pitched concrete slabs and timberwork with a modern design). The ocean swimming pool, however, affirms an abstract language made possible by the use of a modern form of construction: exposed concrete walls and slabs were shown with their rough natural appearance.

The use of exposed concrete ("beton brut" – Siza 2019) in the ocean swimming pool was also in line with the international debate, namely with the ethical and aesthetic brutalist approach of Reyner Banham who was appealing for a modernist urge to create simple and honest buildings based on three criteria: i) clear exhibition of structure, ii) valuation of materials "as found" and iii) memorability as image (Banham 1955). Hence, this approach reacted against the humanist, neo-arts-and-crafts, or decorative architectural trends of that time (Chadwick 2016) and defended an expressive, honest and meaningful use of industrial techniques and materials (such as concrete, steel frames and glass walls), which we can recognize in the ocean swimming pool (Tostões 2016).

Although there are still relatively few sources available in Portugal relating to construction processes and sites (most contractors have not preserved their archives, so that information is often scarce and scattered in nature), this paper nonetheless provides contributions about the construction culture in the 1950s–60s, in a period of transition between continuity with traditional solutions and the affirmation of modern technologies and building sites. However, the present work is limited and shall be further expanded, comparing these building sites' brief analysis with other broader works (Vale 2012; Mascarenhas-Mateus & Veiga 2020, among others).

Finally, faced with an historiography that gives greater prominence to the conception and design (ideas and forms) to the detriment of the actual constructed work (building site, materials, technologies, and actors: architects, engineers, builders, workmen, etc.), it is important to go beyond the history of architecture and architects and delve deeper into the "history of buildings", particularly in terms of their conception and construction processes.

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History of Construction Cultures – Mascarenhas-Mateus & Paula Pires (eds)

Industrialization by CasMez and steel built factories in Southern Italy

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ABSTRACT: The "questione meridionale" refers to the extremely slow industrial development of Southern Italy which has remained a crucial and yet unsolved problem for the entire nation since the proclamation of the Kingdom of Italy in 1861. Henceforth, various governments attempted to find workable solutions through the support for specific institutions in order to advance industrialization. The "Cassa del Mezzogiorno" (Funds for the South) was one such organization that emerged among the initiatives to resolve this problem. This paper aims to connect these events in order to place them in the general scenario of industrialization promoted by Casmez. The goal is to identify the outcomes of the link between architecture for productive spaces and steel structures, highlighting the role played by public institutions and private finance that have frequently intervened in this decades-long process.

1 THE "QUESTIONE MERIDIONALE"

"This country is a mine of mankind; it holds the deepest wealth of men in the world. We have come to discover a new, difficult gold, hidden by nature and history" (Ottieri 1959).

The "mine" to which Ottiero Ottieri referred was the high rate of unemployed or casual workers in Southern Italy who aspired to find permanent employment within the industrial system. Generations who had suffered hardships brought about by the unavailability of regular employment believed their social success could only come about via factory work. The trust they placed in the industrial system led them to believe that only the factory was able to solve the age–old problem of unemployment. The contrast between the rigorous system of rules that governed the factory – "the law of organization" – and the pressing, albeit disorganized demand for their right to work is essential for understanding Ottieri's biographical memoirs, *Donnarumma all'assalto*. The book offers an independent and autonomous portrait of southern proto–industrialism in Italy that went beyond the rhetoric of official apologia not only of the state but also that relating to the famous speeches of Adriano Olivetti given to the workers of Pozzuoli (Olivetti 2012) and Enrico Mattei in Gagliano Castelferrato (Mattei 2002). The book describes some of the contradictions encountered as a result of southern industrial development since the pioneering experiments in the early 1950s. These contradictions were partly due to the distance between the factory, as a temple of the new production system, and the spirit of the workers, which was characterized by their folklore mixed in with despair. Ottieri's memoirs, as a report of his personal experience at Olivetti's factory in Pozzuoli where he worked in staff management, were not the only accounts describing the critical and problematic aspects of southern industrialism. From a different perspective – that of the job seeker perpetually seeking employment – the film *Napoletani a Milano* by Eduardo De Filippo offered another portrayal, albeit in a tragicomic and paradoxical tone, of the uncertain dynamics that accompanied the spread of first industries in southern regions.

As a result of this situation, politicians were forced to adopt suitable strategies to find a solution to this atavistic condition of backwardness, which actually worsened in the wake of national unity. In fact, the subsequent commercial expansion of northern capitalism caused suffering to the few existing southern companies.

The southern backwardness, the so called "*questione meridionale*" (Villari 1878, Franchetti & Sonnino 1877) was a confused mix of problems already present when Savoy forces arrived in the South of Italy, for example the high illiteracy rate of the Bourbon state (Felice 2013), an underdeveloped industrial system mainly supported by public and foreign assets and the absence of a local entrepreneurial class able to achieve manufacturing development (Amatori & Colli 1999). In addition, economic policies adopted after the national process of unification – in particular the protectionism started in 1880 – mainly fostered the commercial interests of northern companies and determined a drastic reduction of southern business that was strictly related to agricultural production (Pescosolido 2004). Some sporadic initiatives undertaken by various governments over the years had tried to solve these complex problems but proved to be ineffective, such as the special legislation that Giolitti enacted at the beginning of 1900, even though this did lead to

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the construction of the Bagnoli steel plant in Naples, the Apulian aqueduct and the "direct" Rome–Naples railway line (Pescosolido 2017).

After the second world war, the Italian government pursued the organic planning of strategies to ensure effective responses to the problems imposed by the "*questione meridionale*". At the beginning of the 1950s the government put forward a series of systemic initiatives to encourage industrial development in the south, under the guidance of the *Cassa per il Mezzogiorno*.

2 SOUTHERN INDUSTRIALIZATION AND THE CASSA PER IL MEZZOGIORNO

The process of industrialization in Southern Italy was initiated in the late 1950s, reaching its peak in the following decade, known as the Italian "Golden Age" (Crafts & Magnani 2011). One of the first official acts to initiate this process was the foundation in Rome of the Association for the Development of Industry in Southern Italy (SVIMEZ) in December 1946. As established in statute art. 2, the main objective of this research facility was the promotion of "concrete action programs […] aimed at creating and developing industrial activities which best met the identified needs of the southern regions and of the large islands". The founders of SVIMEZ were also responsible for launching the *Cassa per il Mezzogiorno* (CasMez), thus Funds for the South. This was established under law 646 in 1950 after Italy's participation in the International Bank for Reconstruction and Development, (BIRS) which was agreed upon at the Bretton Woods Conference in 1944, and granted large loans for economic policies in support of the South (Alacevich 2009). The main goal of CasMez was the economic and social progress of Central–Southern Italy. In order to make this possible, the institution financed infrastructural plans as a pre-condition for future industrial development. Law 646 did not provide incentives for the construction of factories unless they were involved in the agricultural sector. However, the subsequent law 166 of March 1952 did assign the task of supporting initiatives for the building of industrial areas to the Cassa. The institution also dealt with professional development by setting up vocational schools. The area CasMez focused on included that known as the "Mezzogiorno" as well as Abruzzo and Molise and some areas of Lazio and Marche.

Under CasMez's directive, the state recruited "both public companies, obliged by law to allocate a large part of their investments to the South, and private ones, which in exchange received subsidized loans and/or non–repayable grants. These were top–down interventions/investments concentrated in the "heavy" industrial sectors with the highest added value: chemistry, steelmaking and mechanical industries" (Brunetti et al. 2011).

A decisive move to allow CasMez to operate freely was the passing of law 634 in 1957, also known as the Pastore law that introduced the principles of economist François Perroux on *poles de croissance*, namely "growth poles" (Perroux 1957). The law represented a "turning point in an industrialist key" for the economic policy of the Cassa (Parisi 2011). Consequently, CasMez's programs considered two approaches to industrial poles: firstly, the Aree di Sviluppo Industriale (ASI) – industrial development areas – linked to the establishment of consortia for areas where the population was greater than 200,000 inhabitants and secondly, Nuclei di Sviluppo Industriale (NSI) – industrial development clusters – allocating funds to develop less populated areas. Both ASI and NSI embarked on a programme of construction of large industrial areas located in the south namely: Bari, Brindisi, Cagliari, Salerno, Taranto, Gela.

The CasMez activities were structured into five phases: the first three steps being "pre–industrialism" (1950–1957), "industrialization" (1957–1965) and "insertion of regional policy" (1965–1973). These allowed for an effective improvement of the industrial system in Southern Italy resulting in its active participation in the "Italian economic miracle" (Felice & Lepore 2014); the last two, "special projects" (1971–1980), and "extensions lasted until the launch of "AgenSud" (1980–1993) and coincided with a decline in *Cassa*'s activities which mainly stemmed from political choices. Cassa was indeed abolished by the Decree of 6 August 1984 and replaced in 1986 by AgendSud, an agency for the promotion and development of the South, which was itself closed down in 1992 when the Ministry of Economy and Finance decided to take control of public sector interventions in underdeveloped areas.

3 STEEL AND FACTORIES IN THE SOUTH

The funds allocated by the IBRD for CasMez projects in the early 1950s were added to those granted under the Marshall Plan – the European Recovery Program (ERP) – for the modernization of the "main sectors of the Italian export industry" and for policies in support of underdeveloped areas (D'Antone 1995). According to its creator, the US Secretary of State George Marshall, the ERP was conceived as a four–year plan which was launched in 1947. One of its last projects in Italy was the Olivetti factory in Pozzuoli, a new industrial plant built in the South after the Second World War (Labò 1955).

This building is an architectural manifesto of the industrial development of the South. It is no coincidence that its construction received favourable feedback from the media and was repeatedly mentioned in newspapers and magazines of that time (Parisi 2011). The importance placed in it by Adriano Olivetti was demonstrated by his decision to entrust the construction to a Neapolitan designer, Luigi Cosenza, one of the most prestigious southern proponents of the Modern Movement in Italy. The tycoon's confidence in Cosenza, despite the fact he had no experience of building factories, was fully rewarded by the impressive results that led to the construction of

Figure 1. The Olivetti factory in Pozzuoli, L. Cosenza, 1951–54 (Courtesy of www.storiaolivetti.it).

Figure 2. The Montecatini plant in Brindisi, E. Sgrelli, 1960–64 (Courtesy of Archive Giordani, Malaguzzi, Valeri e Sgrelli).

one of the best–known industrial plants in Italian and European architectural historiography (Figure 1). This *début* has been claimed by many over the years to have been a portend for a "magnificent and progressive fate" for southern industrialism. This claim is only partly true because, despite the initial progress of southern industrial development in the "Golden Age" years, Olivetti's foresight and Cosenza's prolific ideas were exceptional forces that have hardly reappeared ever since.

The actions of CasMez, above all the promotion of the ASI and the NSI, with the creation of extensive industrial sites (about 50) and the participation of the state and large northern or foreign companies in the industrialization process, did not favour the growth of a widespread entrepreneurial class able to put forward a consistent number of opportunities for the construction of factories (Castronovo 1993). Significant groups of small and medium–sized enterprises have never appeared in the South, unlike in the North where they have guaranteed architects countless opportunities to explore the design of production spaces.

One reason for this undeniable difference between the two areas is found in the reluctance some southern entrepreneurs demonstrated towards industrial initiatives. For example, this behaviour was stigmatized by Franco Rosi in his film *Hands on the city* when the protagonist declared he preferred residential building speculation to starting up a new factory as the former was far more profitable.

It has been said the South did not offer a lot of opportunity for the construction of industrial architecture, however, this is not entirely true as the realisation of these buildings more often took on a sporadic character. Despite this, some architectural designs have become very well known, such as the Pozzi Ginori plant in Sparanise designed by Luigi Figini and Gino Pollini, the Olivetti industrial complex in Marcianise by Eduardo Vittoria and Marco Zanuso, the SIAG factory, also in Marcianise, by Angelo Mangiarotti, the building Solimene in Vietri sul mare by Paolo Soleri and the Montecatini complex in Brindisi by Ezio Sgrelli (Figure 2). In line with the main technical approach in the southern building sector, these factories were built of reinforced concrete or prestressed concrete technology (Castanò 2010).

A double character of exception represented by the condition of belonging to the group of southern factories and the construction system used concerns steel-built factories. The dry construction technique was marginal in the northern building sector and even more so in the south, where it was relegated to a limited number of architectural experiments. Nevertheless, the exceptional condition southern factories made of steel highlights the interest they present for the history of building techniques. Among them some large industrial complexes, such as the IV steel working plant of Ilva in Taranto, designed by the company's technical office, and the Alfasud in Pomigliano d'Arco by Rudolf Hruska (Parisi 2011). These factories explored the potential of dry construction systems in terms of reducing construction time and flexibility in the structural layout for covering large spans.

These industrial complexes were added to smaller interventions; among them some buildings that appear particularly significant such as the Angus workshops in Casavatore in the province of Naples, designed by Massimo Pica Ciamarra (Figure 3) (Lima 2017), the Brionvega warehouse of Franco Albini and Franca Helg in Arzano (Figure 4) (Manfredini 1972), also in the Neapolitan area, and the SIVAM factory in Battipaglia in the province of Salerno by Franco Sargiani. In this scenario, the architectural experience of Eduardo Vittoria appears particularly significant courtesy of the several steel built factories that he designed, such as the Covit plant in Grumo Nevano and the pharmaceutical laboratories for Farminter and Esterfarm in Pomezia (Vittoria n.d.).

All these buildings resulted from architectural research that tried to translate the design of the factory in a southern manner in order to overcome the stereotype of the northern “black and nameless production workshops” (Ottieri 1959).

An interesting result from this architectural research related to production spaces and steel structures can be found in the distribution centre in Gioia del Colle, designed by Franco Sargiani for SIVAM, not a factory but a working space for industrial system auxiliary services.

Figure 3. The Angus factory in Casavatore, Naples, M. Pica Ciamarra, 1961–1967 (Courtesy of Pica Ciamarra Associati).

Figure 4. The Brionvega warehouse in Arzano, Naples, F. Albini and Franca Helg, 1968 (Courtesy of Fondazione Franco Albini).

4 DISTRIBUTION CENTRE IN GIOIA DEL COLLE

After his degree in Architecture at the Polytechnic University of Milan, Franco Sargiani collaborated with Bruno Morassutti who was the author of one of the most famous Italian steel built factories, the industrial building in Longarone. This experience and a long international internships in several Northern European countries represented a keystone for Sargiani’s career training.

In 1971, he was in his early thirties when he designed the distribution centre in Gioia del Colle.

The building was commissioned from Sargiani by SIVAM, the Italian Agricultural Veterinary Society of Milan, a company that produced feed and chemical products for agriculture and was the owner of the above–mentioned production centre in Battipaglia, which had also been designed by Sargiani. The building in Gioia del Colle, completed in 1972, was intended to house the storage and distribution of agricultural products (Figure 5).

The architect matched the apparent simplicity of the plant with clear design strategies defined on the basis of precise functional and technological needs. The building’s interior, which covered only 2,150 square meters, hosted storage and office spaces with both designed to meet criteria of maximum layout flexibility in order to guarantee the access and movement of heavy vehicles, such as articulated trucks and railway wagons. As a consequence of the flexibility criterion, the height of storage was set to 6.00 m. Storage also had to fulfil specific requirements such as adequate internal ventilation and a low level of lighting in order to guarantee the conservation of agricultural products. An exterior loading and unloading area had to be covered and protected from solar radiation and rain (Figure 6).

Furthermore, the constructive solutions for the perimeter walls had to correspond to specific criteria of durability providing for minimum maintenance and a high level of resistance resulting from vehicle impact.

Figure 5. The distribution centre in Gioia del Colle, Bari, Franco Sargiani 1971–1972 (Courtesy of Franco Sargiani).

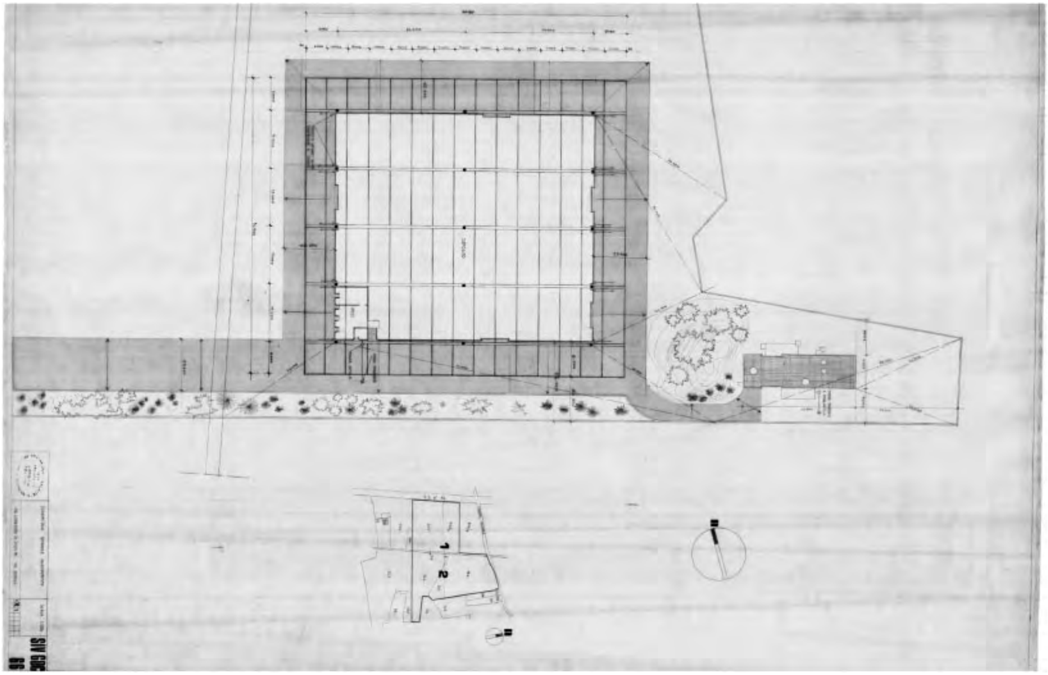

Figure 6. The site plan: the distribution centre and the house of the keeper on the right; the modular grid defines geometric rules for the interior spaces and the perimeter loading and unloading area (Courtesy of Franco Sargiani).

Figure 7. The roof overlapping the thick white walls of the envelope (Courtesy of Franco Sargiani).

Consequently, Sargiani designed a flat roof able to cover both internal and external spaces; he configured the building using two clear architectural solutions: steel components to support the large covering and thick white walls to characterize the vertical envelope (Figs. 7, 8).

The storage plant is defined by a grid, based on the modules M11 and M4, that established the rules for the

Figure 8. The construction of the envelope: internal reinforced tuff block walls (Courtesy of Franco Sargiani).

Figure 9. The steel structure contained within the wall perimeter (Courtesy of Franco Sargiani).

modular design: each column is placed 11 meters apart on one side and 24 on the other (Figure 9). Columns are composed of section bars welded together; with each supporting a coupling of two trusses, 2.50 meters high, which cover two spans of 24 meters and end at both sides with overhangs of 6 meters. Truss members are I shaped profiles, angles and channels; they support a sequence of underlying transversal beams spaced 4 meters apart (Figure 10). These form the roof structure which is composed of lightweight composite panels of polyurethane foam externally finished in pre–painted metal sheet.

The thick vertical envelope, of internally reinforced tuff block walls, is 10 cm lower than the roof and separated from the columns. In particular, the relationship between walls and columns are alternatively resolved along the perimeter: on two parallel sides, the columns are external and the wall envelope is interrupted only by the entrances; on the other sides, the columns and walls are detached through the interposition of glass panels. This solution also characterizes the front section that corresponds to the office area (Figure 11).

The detachment between the envelope and the roof highlights the structural lightness and the iconic value of the cover solution. In particular, this detachment produces an empty strip only covered by a grill allowing adequate internal ventilation. The trusses on the roof sit slightly above the long skylights which guarantee the required level of lighting within the building.

Figure 10. A couple of steel trusses and the sequence of underlying transversal beams (Courtesy of Franco Sargiani).

Figure 11. The building façade corresponding to the offices: the detachment between envelope and roof highlights the different nature of the building components (Courtesy of Franco Sargiani).

5 CONCLUSIONS

The southern dream of a massive transition from an agricultural and artisan matrix to a modern industrial system took place within the dynamics promoted by Casmez. From the beginning, its development strategies followed two paths: public interventions and private initiatives even though supported by huge public funding. The implementation of numerous multi–year programs financed by Casmez led to the modernization or the new construction of infrastructural networks and industrial complexes that have spread to the "*Mezzogiorno*". Consequently, the factory, a new temple of industrial society, appeared in areas mainly suited to agriculture. In this scenario, the steel structure always represented an alternative and marginal option from a technological point of view.

The shortcomings in metal construction diffusion related to sector policies not only influenced by local economic and productive contexts but also linked to the general dynamics and political choices that involved the entire country. However, steel structures for production spaces represented a turning point in terms of the advancement of construction techniques, renewing the traditional building practices of underdeveloped areas. The dry construction system was in fact combined with architectural research that showed future scenarios for the building sector in Southern Italy. In the case of large industrial areas, the use of steel structures mainly concerned the technical aspects and defining flexible layouts, while in small production complexes the research on metal constructions was functional for defining the spaces that would reinterpret the nature of these places. This was one of the fundamental requirements for achieving a southern way to design factories.

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History of Construction Cultures – Mascarenhas-Mateus & Paula Pires (eds)

The ‘exact fantasy’ of steel: The impossible mission of *Costruzioni Metalliche Finsider* (CMF)

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ABSTRACT: In the history of Italian structural engineering, monopolized by reinforced concrete, steel also experienced a moment of glory. It happened during the boom years: in the affluence that had now been achieved, when even the most expensive material for Italy, which had always lacked in iron mines, seemed to become competitive. In such a peculiar context, in the 1960s, surprisingly enough, a ‘state’ company was founded within IRI with the ambition of monopolizing this market, which was expected to be profitable and expanding: Costruzioni Metalliche Finsider, known by its acronym CMF. This venture stemmed from complex reasons concerning the political, economic, and productive history of Italy: this contribution aims to reconstruct the genesis and failure of this “state attempt” to impose steel on Italian structures. The survey makes use of unpublished archival documentation (the private archives of the CMF designers, IRI files at the Central State Archives, client archives) and unexplored photographic files. This work forms part of the SIXXI project (ERC Advanced Grant, P.I. T. Iori, S. Poretti; host institution: Rome Tor Vergata University).

1 INTRODUCTION

The heavy investment in the steel sector in post-war Italy is well known as is also how Finsider, the financial company in the IRI group steel sector, was a key player in driving the change of pace inn this industrialization. Oscar Sinigaglia, president of Finsider in the immediate post-war period, in as early as 1949, launched a plan (later called the ‘Sinigaglia plan’) for restructuring the controlled iron and steel plants, which mainly used scrap, instead favouring the building of full-cycle plants, directly based on imported ore. Thanks to favourable diplomatic negotiations, the company obtained important funding under the Marshall Plan to build a new large plant in Cornigliano, which started up in 1953 and marked the first decisive moment of exponential growth in the Italian steel industry. Once production had been boosted, all that was left was to stimulate steel consumption by encouraging the increased use of steelwork in buildings, bridges and large roofs. To this end, Finsider decided to directly approach the field, launching an ad hoc company: 22 February 1960 was the official founding date of “Costruzioni Metalliche Finsider S.p.A.”, which was set up with share capital of 60 million lire. The articles of association state that “the company’s purpose is the study, design, execution and sale, both in Italy and abroad, of metal structural works”.

To ensure that the inexperienced company was as efficient as possible, both technically and economically, Finsider enlisted the support of the most successful North American steel company, the United States Steel Corporation (USS), which was at the forefront of the steelwork industry thanks to its subsidiary, the American Bridge Company, which had, in 1957, completed the production and construction of one of the longest suspension bridges in the world, over the Straits of Mackinac, designed by David Steinman.

The interests of Finsider and USS were intertwined: CMF needed a guide to conquer this mysterious new world, and USS, in addition to betting on increasing the usage of steel in Italy in large structures, wanted to expand overseas and gain access to the European market. Contacts began immediately and the agreement was signed on 24 September 1962: the USS Corporation took equal control of CMF with Finsider, providing technical assistance and know-how. The economic investments underlying the agreement were considerable and all aimed at building a new, modern factory (which was duly inaugurated on 1 January 1965 in Guasticce, Livorno) with an initial production capacity of around 70 thousand tonnes per year but with the ambition of reaching 100 thousand tonnes. All the conditions for success were in place.

2 FROM FIRST STEPS TO THE CMF STYLE

In the meantime, the technical management of CMF was entrusted to Fabrizio de Miranda, 34 years old in 1960 but already with a great deal of experience in the Bossi metal carpentry workshops, and then as the 1958 designer of the only two steel viaducts on the Autostrada del Sole, the Coretta and the Macinaie (Figure 1).

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capitale:
50% FINSIDER s.p.a.
50% UNITED STATES USS STEEL CORPORATION

CMF

Figure 1. CMF – Costruzioni Metalliche Finsider. Company logo (Andrea Goldstein Bolocan Private Archive).

The first important orders came “from within”, in what can be defined as a “privileged market” to all intents and purposes, without tenders and without competition: in fact, the most important public companies controlled by IRI, especially those just established, commissioned CMF to build their headquarters following rapid private negotiations. This led to the construction of the RAI headquarters in Rome, designed by Berarducci and Fioroni (1961–1967) and the RAI headquarters in Turin, by Morbelli and Morelli (1963–1968), the Alitalia headquarters in Rome, by the Valtolina Rusconi Clerici technical studio (1966) and the SIP skyscraper in Genoa, by Bega, Gambacciani, Viziano (1966–1970).

Outside the IRI galaxy, other public companies or companies interested in maintaining good relations with the state brought ‘easy’ work. These included the twin headquarters of Esso Standard Italiana High (1964–1965) and Società Generale Immobiliare (1965–1966) in Rome’s EUR district, designed by Moretti and Morpurgo; the nearby headquarters of the Istituto Mobiliare Italiano, in particular the volume designed by La Padula and Marchini (1967) (Figure 2); for the hotel of the Jolly chain in Vicenza on Corso d’Italia, by Monaco with the collaboration of Covre (1964–1971); the headquarters of the

Figure 2. Rai headquarters in Rome during construction, 1961–1967 (A. Goldstein Bolocan Private Archive).

Figure 3. Humanities faculty of the University of Turin during construction, 1965–1966 (A. Goldstein Bolocan Private Archive).

Humanities Faculty of Turin University (1965–1966), by Levi Montalcini and Morelli, in addition to many other buildings for public institutions, including the Palace of Justice in Genoa (1967).

These buildings underpin the recognition of the typical characteristics of the 'CMF style'. At a time in Italy when the structure was exhibited, even ostentatiously, and becoming, thanks to the international recognition of Italian reinforced concrete engineers, one of the key points in the architectural language, the steel frame proposed by CMF was instead resigned, hidden, almost annulled behind the modern envelope of the curtain wall. This is because it is strictly "functional": it is the industrial frame, simple, cheap because it is repetitive, quick and easy to assemble, which became popular worldwide, especially in the United States, starting with the first skyscrapers. Welding on site, which was left to the worker's skill, was almost completely abandoned, and the construction site became truly "dry", based exclusively on bolting. However, this solution allows for neither error nor adjustment (Figures 3–5).

3 FLYING ROADS

However, it was not by constructing well-hidden frames in buildings that steel would displace

Figure 4. Assembly stages of SIP skyscraper in Genoa, 1966–1970 (A. Goldstein Bolocan Private Archive).

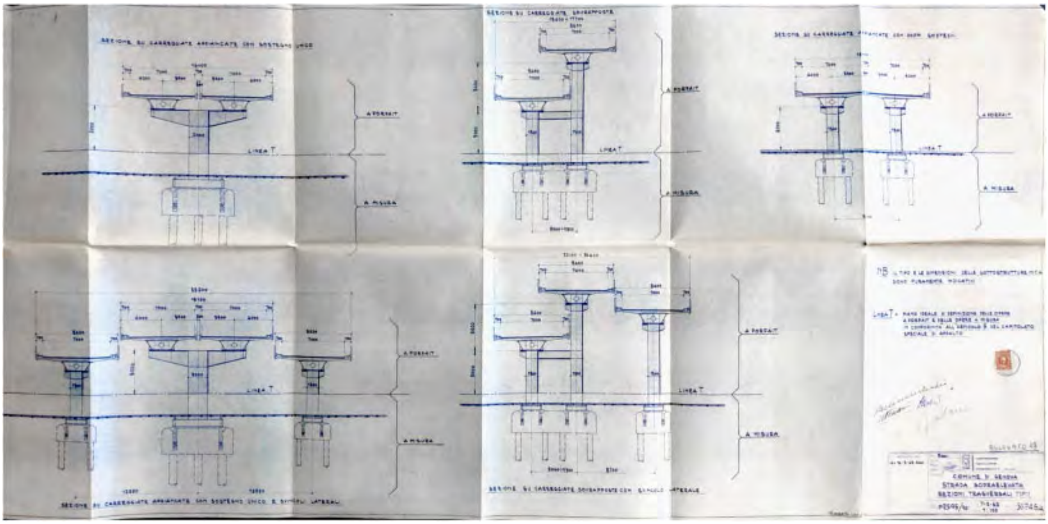

Figure 5. Genoa flying road type cross-sections, 2 February 1962 (Historical archives of the Municipality of Genoa).

Figure 6. Genoa flying road, 1961–1965 (free on Internet).

reinforced concrete: it was necessary to come out into the open, to publicise the potential and advantages of steelwork by exhibiting it. And for "communicating" the CMF style, infrastructure was more appropriate.

The opportunity arrived with the Genoa elevated road, a ribbon that crosses the entire city and with which to show off the strengths of the material and modern technology: speed of execution, competitive costs thanks to the repetition of the modular span, and minimum space requirements.

The municipal technical offices drew up an outline project in as early as October 1960, adopting a traditional reinforced concrete structure and proposing to the administration that a call for tenders be issued. It was on 20 July 1961 that CMF stepped in and made a proposal to the City to build the entire route in steel. In Genoa, Italy's steel capital, the proposal sounded particularly good (Figures 6, 7).

The administration appointed an expert commission to examine the economic, technical and urban planning aspects of the CMF project which, given the urgency, was completed in just 55 days. A fast traffic route in a strategic area running for kilometres in parallel to the historical buildings of old Genoa and the port: the light and minimal solution of a single T-shaped central pillar supporting the lanes on two cantilevered brackets overcame any doubts about landscape protection. On 16 March 1962, the work was awarded to CMF by private contract. The elevated thoroughfare was built, and in steel.

The artery is raised on pylons, repeated identically more than 200 times, spaced 20 metres apart and extending along a route of about 4,600 metres. The project was designed by De Miranda, and the construction system adopted for the deck was the “Verbundbauweise”, i.e. a mixed steel-concrete system where the reinforced concrete slab and the steel beam form a single static element.

Figure 7. Genova flying road during the construction, 1961–1975 (Ansaldo Historical Archive).

The work proceeded quickly: the pylons arrived at the site already assembled, at night and so without the need to interrupt traffic. They were lifted by crane trucks and fixed to the anchor bolts: from that moment on, everything took place in the air, with the construction site raised from the ground, without the need for any temporary scaffolding. Assembly work began on 12 February 1964 and the elevated artery was inaugurated on 6 September 1965. The most effective publicity derived from a documentary on the construction of the ‘flying runway’, the text of which describes the ‘installation as a staging … of the exact fantasy of steel’.

In the meantime, another adventure destined to leave its mark was underway: the Tangenziale Est (East Orbital Road) of Rome. Already envisaged in the new 1962 urban development plan, with a total length of 7.7 kilometres, this was a much sought-after project for CMF, because in addition to confirming the success of Genoa, it would gain the opportunity to claim some sort of ‘specialist qualification in flying roads’.

On 11 September 1967, CMF was entrusted with the design and construction of the crucial section, the ninth: the Scalo Merci San Lorenzo viaduct. Work began in 1969 and was completed in 1972. As in Genoa, the mixed steel-concrete system was used but everything was much less “exact” (Figures 8–11).

The steel beams, welded in the workshop, contain a rectangular cross-section, with spans ranging from 20 to 76 metres in length, and run in parallel, resting on tubular steel pylons. Due to the convoluted geometry of the route, there were also special solutions, especially near junctions, for example with high central pylons cantilevering the two carriageways, which are arranged at different heights. However, the stretch of

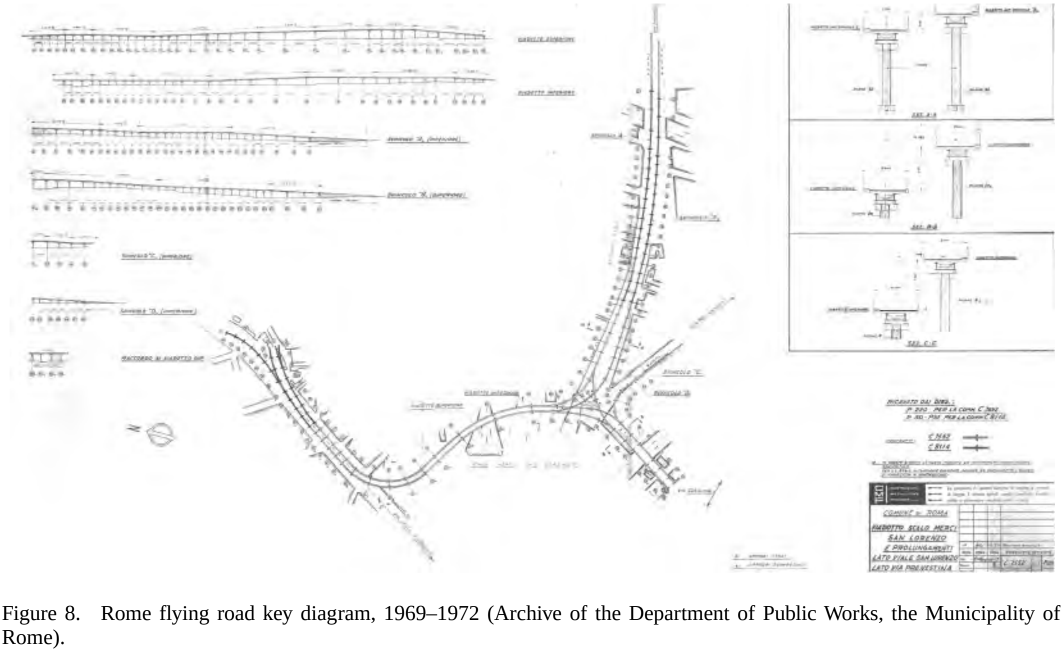

Figure 8. Rome flying road key diagram, 1969–1972 (Archive of the Department of Public Works, the Municipality of Rome).

Figure 9. Rome flying road during the construction, 1969–1972 (Ansaldo Foundation Historical Archive).

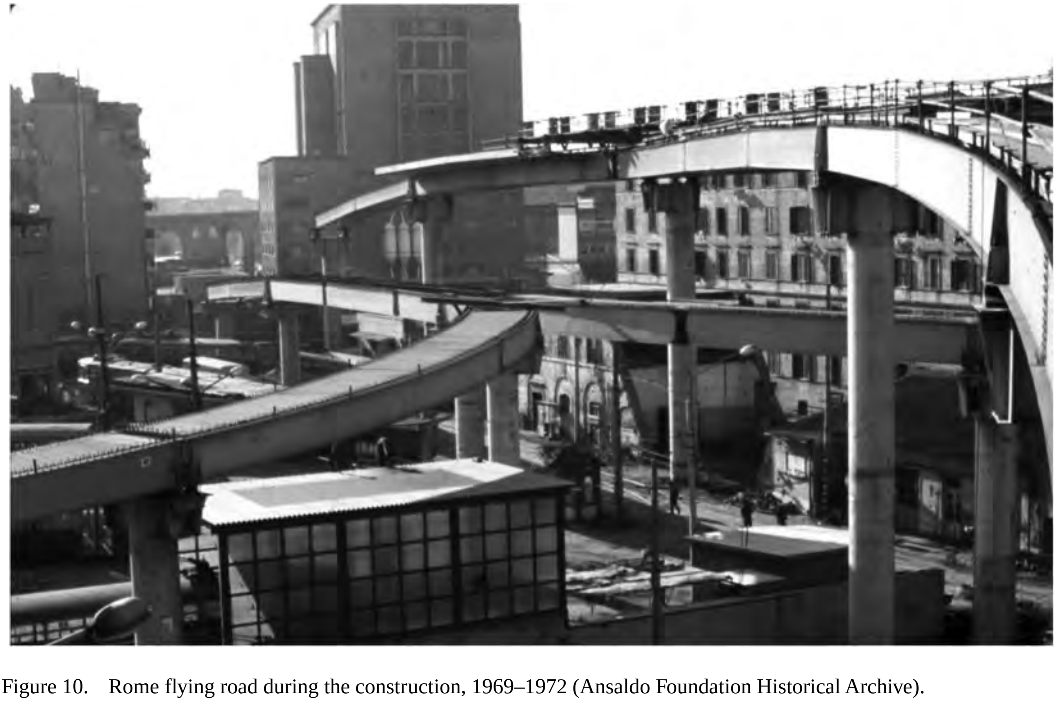

Figure 10. Rome flying road during the construction, 1969–1972 (Ansaldo Foundation Historical Archive).

Figure 11. Rome flying road during the construction, 1969–1972 (Riccardi Historical Archive).

road remains one of the least popular in Rome, as it borders too closely on the existing buildings near Viale Castrense.

4 THE BEGINNING OF THE CRISIS

At the end of the boom, in the second half of the 1960s, the market development forecasts that had been the basis of the joint investment by the state and its American partner were completely overwhelmed by reality. A deep and widespread recession obviously also affected the metalworking sector: the number of orders did not increase but rather dropped far enormous to cause a large surplus in production capacity.

In the civil construction sector, steelwork did not at all undermine the dominance of ordinary and prestressed reinforced concrete, which was in any case more suited to Italian construction companies. Also in the infrastructure sector, CMF was never able to win truly ‘open’ competitions as the American system did not favour adaptation to complex geographical situations through unique solutions: it was no coincidence that, along the Salerno-Reggio Calabria motorway, the production and vacuum assembly of the metal truss for the Italia viaduct over the Lao was entrusted to Badoni, based on Covre’s designs; and the ‘rotating’ pier frame of the Sfalassà was produced by Savigliano to a design by Zorzi.

Even abroad, market opportunities were much lower than expected, partly due to competition from Italian construction companies pushed out of the country by the national contraction of investment in public works. Instability and uncertainty undermined relations with the USS and led to the latter’s definitive exit from the CMF (August 1967).

It was the Indian bridge in Florence that was the last major work to be carried out by CMF: a steel cable-stayed bridge, the first example in Italy of a large span (206 meters), built between 1973 and 1978. The parts were prefabricated and welded at Guasticce and then transported and bolted at the construction site, but the “repetitive fantasy” of CMF’s style was no longer present. The work was even awarded a prize in 1978 by the CECM (European Convention of Metal Construction) for its static and constructional originality, sanctioning the annulment of the very assumptions on which the partnership with the Americans was based. CMF broadly disappeared from the scene but remained active until its liquidation in 1998.

5 CONCLUSION

With the failure of CMF’s mission, the exploits of steel in the history of Italian construction also came to an end: there will still be other “posthumous masterpieces” of course but they will once again be isolated episodes in a sea of concrete works. Thus, a short chapter that began at the height of the boom and ended just before the great world energy crisis of 1973.

The basis for the failure of CMF, which was founded to "consume steel" and bring the country into line with global industrialized construction methods, arose from its anti-craft genesis and clearly tells how far the Italian School of Structural Engineering was from the international language. Its construction sites were rapid, rational and precise but, precisely because of this, they found little room in the anomalous national process of industrialization.

The question remains as to how an American company, still today one of the world's most important, could have been so clueless as to invest capital in a venture as ruinous as the Italian case, losing several million dollars. One hypothesis is that it was attracted by the dream of building the legendary bridge over the Straits of Messina. After all, the "Gruppo Ponte di Messina" company was founded in 1955 with this very aim and, among the group's strongest subsidiaries, was of course Finsider, while the most credible project was presented in 1953 by Steinman.

Perhaps USS wanted to be ready, with factories on site in full and adequate production. However, this backstory, fuelled by a luncheon organized by the USS in honour of Prime Minister Fanfani, on the occasion of his official visit to Chicago on 18 January 1963, a meeting at which the bridge and the importance of American aid were allegedly discussed, has yet to be proven.

For the time being, we will limit ourselves to recognizing the "American-style" works actually left on Italian territory by CMF: the steel serpentines winding through the cities of Rome and Genoa and the hidden frameworks of the "international style" buildings that contribute to delineating the portrait of a key moment in the Italian School of Engineering: one that anticipates its unstoppable decline.

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Oneri a carico dell'IRI secondo gli impegni assunti relativamente all'iniziativa CMF a Livorno, 23 October 1962, fasc. III.

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Verbale 11a riunione del CDA della CMF, 16 January 1963. Realizzazione a Livorno del nuovo grande stabilimento di carpenteria, 19 April 1963, fasc. III.

Verbale 21a riunione del CDA della CMF, 29 March 1966. Accordi per il recesso della USS dalla CMF, 3 August 1967, fasc. III.

Sopraelevata. Una strada d'acciaio, 1968. 20'. Color. Director: Valentino Orsini with Lionello Massobrio, text: Franco Fortini. RPR.

Studio per la scelta ubicazionale di un nuovo stabilimento, 26 May 1962, fasc. III.

History of Construction Cultures – Mascarenhas-Mateus & Paula Pires (eds)

A concrete story: The 15-year collaboration between Harry Seidler and Pier Luigi Nervi, 1963–1978

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ABSTRACT: Harry Seidler (1923–2006) and Pier Luigi Nervi (1891–1978) first met in Paris in 1955 on the construction site of the UNESCO Headquarters, which was designed by their mutual friend, Marcel Breuer. Seven years later, the two met again, although this time in Rome to study the design planned for the iconic Australia Square Tower. Later, from 1963 to 1978, Seidler engaged Nervi as a consultant for the design of several commissions. Through discussion of the events that have surrounded and revealed the design and constructional aspects of the Nervi-Seidler projects, this paper examines the role of their professional collaboration in the work of the Australian architect and, simultaneously illuminates the last period of Nervi's career, the so-called "third life".

1 INTRODUCTION

"To work with Pier Luigi Nervi [1891–1978] (…) as I have done for a period of 15 years, is not only a sobering experience but virtually an education in itself" (Seidler 1981: HSA Box 11). It was with these words at the opening ceremony of the Nervi Exhibition in Australia 1981 that Harry Seidler (1923–2006) honored the inspirational effect that the Italian engineer had on his professional life. An influence fostered by the shared feeling that only through an "elevated degree of satisfaction of the functional, technical and constructive requirements" was it possible to achieve a valid aesthetic result, as Nervi stated about his collaboration with Seidler in 1978 (Nervi 1978: PLN, MAXXI: P108/8).

The pair met for the first time in Paris in 1955 on the construction site of the UNESCO Headquarters, designed by their mutual friend, Marcel Breuer. In this same year, Nervi was completing his seminal book *Costruire Correttamente*, while preparing for two new design challenges which were soon to become the symbols of post-war modern Italian architecture: the Palazzetto dello Sport in Rome (1956–1957); and, the Pirelli Tower, which Nervi designed with Gio Ponti in Milan (1955–1959). Conversely, after immigrating to Australia in 1948, Harry Seidler had already built a collection of residential projects, first examples of modernist architecture in Australia, of which, in less than seven years, he became the principal representative and ambassador.

Following their initial brief encounter in Paris, Seidler and Nervi reacquainted seven years later in Rome to work on the design for the iconic Australia Square Tower (1961–1967). Proceeding this first professional partnership, Seidler engaged Nervi from 1963 to 1978 for the design of several other commissions. Nervi's contribution and collaboration were always acknowledged by Seidler, even in the design of the buildings with which Nervi did not directly work, yet the enduring influence of the Italian master was palpable. Therefore, following the years with Walter Gropius and Marcel Breuer as a student at Harvard and a brief but significant working experience with Oscar Niemeyer, Nervi had become Seidler's fourth teacher or, as in Peter Blakes's words, a "catalytic figure who played a decisive role" in the long career of the Australian architect, as also exclaimed by the historian, Kenneth Frampton (Blake 1973; Kenneth et al. 1992).

The Nervi-Seidler collaboration occurred in a period of great professional challenges and changes of their respective lives (Figure 1). Historian Sergio

Figure 1. Harry Seidler and Pier Luigi Nervi, Rome 1972. © Penelope Seidler (photographer unknown).

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Poretti stated that Nervi was in fact starting his “third life” during this time and that by means of his son’s office in Rome – Studio Nervi – he capitalized on his worldwide success by participating in an abundance of international commissions (Poretti 2017). Conversely, with acknowledgements to the numerous and increasingly more demanding Australian projects, Seidler was maturing his education into a sound expert practice

2 METHODOLOGY

This research relied heavily on archival investigation. The first investigation has been carried out by cross-referencing the four main archives in which literature presenting the Seidler-Nervi collaboration is conserved. This proved to be difficult, as the archives are divided between Italy and Australia. Specifically, the sources and documents referred to for this paper are conserved at the State Library of New South Wales (SLNSW); Harry Seidler & Associates office in Sydney (HSA); Pier Luigi Nervi Collection at the MAXXI museum in Rome; Italy (PLN, MAXXI); and, Centro Studi e Archivio della Comunicazione, Parma, Italy (CSAC).

3 THE EARLY SEIDLER

Seidler studied architecture at the University of Manitoba, Canada, and after his graduation was accepted into a postgraduate course run by Gropius and Breuer at Harvard. Following two years of study, it was here where he received his master’s degree in 1944. Seidler shortly after travelled to South America, where he worked briefly with Niemeyer, before moving to Australia in 1948. The exposure to masters such as Gropius, Breuer and Niemeyer inevitably had a direct influence in the making of Seidler as the ambassador of the Modern Movement in Australia.

Seidler’s early success in Australia started with the construction of Rose Seidler House, Wahroonga in 1948–1950, which led to design of a series of houses, all of which featured aesthetic and functional precepts of modern architecture as dictated by Gropius, who Seidler invited for the 1954 RAIA Convention and Exhibition as a guest. However, despite the professional success attained by his residential projects, Seidler was eager to experience other parts of the world to examine and understand the evolving trajectories of architecture. Thus, he decided to pursue his first of many expeditions around the world. In preparation for his first trip, Seidler wrote to many leading architects with the request of visiting their offices to appreciate firsthand their work and design approaches. During a sojourn in Italy, he wished to visit Nervi in Rome and Gio Ponti in Milan. So, on 28 October 1955 Seidler wrote to Nervi (SLNSW: MLMSS 7078/2). However, as Nervi was away during Seidler’s visit of the Studio Nervi in 1955, only later that year once in Paris was Seidler able to personally meet Nervi on construction site of the UNESCO Heritage building for which Nervi was collaborating with Breuer as the structural engineer.

Once back in Australia from 1957 to 1961, Seidler continued working under the influence of rigorous modernism, as is evident in the strict rationality expressed in his designs of the Ithaca Gardens apartments (Sydney, 1960) and Blue Point Tower (Sydney, 1962), commissioned by Dick Dusseldorp. Nevertheless, these two projects allowed Seidler to gain a profound knowledge of construction of tall buildings, which in 1963 led to him being appointed by the same client as the sole architect for the Australia Square Tower in Sydney, for which Seidler involved Nervi as a structural engineer.

4 STUDIO NERVI AND THE NERVI STYLE

In 1952, the appointment as the structural engineer for the UNESCO building, together with Bernard Zehrfuss and Marcel Breuer, was, for Pier Luigi Nervi, the climacteric of international recognition as a prominent figure in the modern architectural landscape. Nervi, already renowned in Italy, gained international acclaim following the construction of the Hall B, Turin Exhibition (1947–1948). Built to celebrate 150 years of national unity in Italy, Hall B features a 3 cm thick, perforated concrete vault spanning 90 meters made of a series of thin ferrocement of undulating arches. The vault was completed with an intricately ribbed half-dome which flaunted the sculptural plasticity of the concrete and its formidable flexibility. The Hall B building endures as a potent architectural image of structural expressionism and through its design and construction Nervi was able to synthesize his extensive research on reinforced concrete as architectural and structural material which began in the 1930s.

In the same year of his appointment for the UNESCO building, Nervi joined his son Antonio’s office, Studio Nervi. Nervi’s distinction, coupled with the energy of his young son, Antonio (1925–1979), granted Studio Nervi involvement in many foreign commissions. These were often carried out with local structural and architectural firms, all eager to have Nervi as an associate in their projects. Among the many, the Norcia Cathedral in Perth (1958); the George Washington Bus Terminal in New York (1962); the Field House at the Dartmouth College (1962); the Tour de la Bourse in Montreal (1962); the San Mary Cathedral in San Francisco (1966); and, the Good Hope Centre in Cape Town (1970) portray the triumph of Studio Nervi throughout the world. By 1972, Studio Nervi was comprised of an impressive team of 21 technical staff (Poretti 2017).

Throughout Italy and abroad, Nervi was known for his engineering ability to design and construct complex structures such as stadia, gymnasia and factories. The functional aspects of these buildings were generally simple, so the static solutions were usually prominent in informing the resulting spaces and architectural image of the same. As a result, architecture and structure would often coincide, yet the role of the architect was often subordinate to that of the engineer. The structural resolution became the formal architectural expression, and so structural expressionism promptly became an architectural language. Nervi's elaborate, interlocking domes and slabs and solitary silhouettes of his doubly ruled columns befitted pure architectural shapes, geometries that could be applied regardless of their actual static function. Namely, Nervi's buildings established a structural inspired architectural style which could be applied to any building, regardless of the scale or the structural requirements. His design approach could imbue single structural elements to communicate with architectural shape the internal flow of forces to thus achieve an expressive structural language. Unlike his fellow engineer contemporaries, who were involved entirely in the research of structural efficiency and the design of thin concrete shells booming at that time, Nervi was primarily intrigued by the sculptural and constructional potential of the use of concrete in architecture. Consequently, his work transitioned beyond the bounds of pure engineering into the artistic realm and eventually developed into a signature style today known as Nervi Style. It is therefore unsurprising that Seidler, who adhered to the rationalism of modern architecture, registered at his first sight of Nervi's shells in Rome that they were "fussy decorations" (Seidler 1955: SLNSW, MLMSS: 7078/2).

By combining the original Nervi Style and the constructional knowledge, developed and refined throughout Nervi's 30 years of research on engineering and construction, Studio Nervi was not only able to overcome the Italian national economic crisis of the 1970s but also the end of the great popularity and experimentation on concrete shells, so while a pivotal figure of modern engineering such as Candela was without commissions of any kind at end of the 1960s (Tang 2012), Nervi's Rome office was flooded with requests of collaboration the world over.

Nervi's stylistic approach allowed Studio Nervi to work with a certain degree of flexibility in working on either an entire building or merely a single aspect of the same. The latter approach was often the case for the collaboration with Seidler who, after having fixed the preliminary scheme in conjunction with local engineers, sought a final refinement from the Italian master. As a result, many structural profiles adopted in the Seidler buildings – such as Australia Square (Sydney, 1961–1967); the MLC Centre; the Theatre Royal lobby (Sydney, 1972–1978); the CTA Business Club (Sydney 1973–1975): the TGO (Edmund Barton Building) (Canberra, 1970–1974); and the Australian Embassy (Paris, 1973–1975) – were designed with the collaboration of Nervi's office.

The collaboration was predominately expressed through the exchange of sketches, drawings and letters. Nervi did not speak English, and Seidler did not speak Italian, and therefore verbal communication was minimal. However, despite the language barrier, the collaboration was meaningful and based on a profound professional esteem. Furthermore, Nervi's son Antonio, who was only two years Seidler's junior and trained as an architect, like Seidler, played a crucial role in the 15-year partnership. Indeed, most of the correspondence and meetings were directly managed by Antonio himself, and only occasionally by Nervi.

5 THE 15-YEAR COLLABORATION

5.1 *Australia square: Structural art and permanent formworks*

Australia Square Tower was the first project designed by Seidler in collaboration with Nervi (Stracchi 2019). In 1963, following Nervi's acceptance for working on the design of the tower, Seidler sent a set of preliminary drawings to Nervi to be reviewed and modified "substantially" if deemed necessary (Seidler 1963: PLN, MAXXI: P60/12).

The preliminary structural design conceived by local Australian engineers adequately solved the general static problem of the unusual cylindrical tower. Consequently, Nervi's contribution was eventually limited to the design of the precast spandrels, the shape of the outer columns forming the tower's exoskeleton and their precast formwork system, and the lobby and trade floors, which were fashioned with the unmistakable Nervi Style. Moreover, the two floors were built by adopting the famous Nervi System of modular ferrocement panels, which were to be used as permanent formwork. Both design and construction solutions were quickly defined in a few meetings held in Rome, between October and November 1963. Both columns and ribbed floors were designed to fully express their structural function, but not strictly out of any structural necessities or optimization. The Nervi slab was the most structurally inefficient aspect of the tower, and the only part not built with lightweight concrete as Nervi was not familiar with the material. However, despite its structural inefficiency, the slab became the emblem of the tower, an artwork in itself that equated with the Le Corbusier's tapestry (today replaced by a Sol LeWitt's mural, *Bars of Colors*), and Calder's *Crossed Blades* composition. With acknowledgements to the powerful shots taken by Max Dupain in 1967, the ribbed slab and the tapering columns became the trademark of the building, which soon gained the most prestigious Australian architecture awards and public success (Figure 2).

Additionally, in 1966, Nervi's precast spandrels, column casings and the ribbed slab were presented in *Constructional Review*, the official magazine of the Cement and Concrete Association of Australia as "novel techniques". In fact, before Australia Square, despite the great costs of the formworks in the flourishing concrete industry, there was very little technical discussion surrounding the formwork. Used as precast

Figure 2. Australia Square through the keyhole, 1975. © Penelope Seidler (photographer Max Dupain).

concrete casings, the permanent load-bearing formwork of the columns were subsequently developed and perfected by Civil&Civic (Australia Square's builder), who applied this same type of construction to buildings erected in Hobart, Canberra and New Zealand. The magazine presented details of the formworks which, as stated, allowed for the cost of the 50-floor office block development to be in keeping with that of a 15-storey prestige building ("Concrete in Building" 1966).

Both the architectural and constructional success of the tower rewarded Seidler's intuition and audacity in involving Nervi in the design of one of the first towers built in Australia. As a result, Nervi became Seidler's structural design consultant for many other commissions.

5.2 *Trade government offices: Logical expressions, replicas and variations*

A few years after the completion of Australia Square, Seidler was commissioned with the design of the Trade Group Office (Edmund Barton Building, 1970–1973) in Canberra. Envisioned as a bridge-like building so to relieve the ground from any visual impediment. Seidler asked Studio Nervi to design the main structural profiles necessary to suspend the building from the ground. As a result, Studio Nervi provided the design for the "T" and "I" beams that feature in the suspended façades of the building (Figure 3).

In his introductory lecture for the exhibition on Nervi's work, held in Australia in 1981, Seidler recalled the engineer's sentiments regarding the logic behind the beam profiles: "'stresses don't go around corners . . . Willingly", he [Nervi] said and proceeded to sketch a graceful gradually transitional form. It proved to be far more expressive and logical" (Seidler 1981. HAS: Box 11). However, the resultant beams' silhouettes inspired by the flow of forces passing along the span were considered a matter of personal taste, rather than of an absolute structural condition. The language adopted for the two beams for the TGO demonstrated how design philosophy underlines Studio Nervi: whereby static logic is exploited to achieve architectural aesthetic strength, regardless of actual or strict structural necessities. Consequently, although there was an increase in complexity for manufacturing single elements, the giant structural shape on the base of an optimal – but not absolutely necessary – material arrangement alone enriched and softened the stereometric composition of the office building, while nevertheless allowing the overall function and construction logics to be maintained. As a result, despite the skepticism expressed on Nervi's work during his sojourn in Rome in 1955, and after the success of Australia Square, Seidler became increasingly fascinated by the logic of the structural language supporting the stylistic approach of Studio Nervi.

Figure 3. Implementation of the Nervi's "T" and "I" beams at the TGO building (today Edmund Barton Building), 1973. © Penelope Seidler (photographer Max Dupain).

The TGO structure was completed with two small detached buildings: a conference hall and a cafeteria. Positioned within the two open courts of the buildings, the display of the corresponding two roofs would have certainly enriched the visual experience of the workers as sought by Seidler. Despite the relative structural simplicity of the two structures, the architect requested Studio Nervi to prepare a design proposal for the same, stating "I look forward very much to you [Antonio] and your father's reaction for this small but very important building (…)" (PLN, MAXXI: P108/8). Eventually, Studio Nervi submitted three design options for the roof of the Conference Centre, and one design option for the roof of the Cafeteria. However, due to financial reasons, none of Nervi's design schemes was built, and the buildings that were realized instead adopted a tidier design.

Australia Square and the TGO projects proved to Seidler that he could rely on Studio Nervi, not necessarily as a structural specialist, but essentially as an architectural design consultant. Indeed, the visual appeal of the Nervi Style was becoming a far greater consideration than any construction or structural concern, which could easily be solved in Australia regardless. Therefore, when the costs were not prohibitive, Seidler always sought suggestions from Rome and endeavored to implement them accordingly.

The TGO was also the first large scale project designed by Seidler and the structural engineer Peter O. Miller. The progressive engineer who, together with Seidler, had visited Nervi's office in Rome in 1955 and on several other occasions during the Seidler-Nervi collaboration, served to play a critical role in the refinement of the structural design of the TGO and other commissions. Indeed, it was Miller who calculated the construction of Nervi's "T" and "I" beams for the TGO, the designs of which were subsequently replicated (although adjusted) for the design of Milson Point Office building (Sydney, 1971); the Fairfield Municipal Library (1976); and the Garden Island Dockyard Workshop (Sydney, 1985), projects that adopted variations of Nervi's structural profiles for the TGO's beams. These buildings pay homage to the tacit consequence and influence of the Seidler-Nervi collaboration. Furthermore, within Seidler's collection of work, the enduring professional partnership between himself and Miller exemplifies the devotion that Seidler always dedicated to the role of engineering in the ideation and expression of his architecture. An exceptional consideration that was undoubtedly instilled in Seidler by Nervi.

Figure 4. MLC Tower – Nervi's column profiles and beam-spandrels (cropped). © Penelope Seidler (photographer Harry Seidler).

5.3 *MLC centre and CTA building: Static limits and aesthetical aspects*

From 1955 to 1970 Nervi was completely involved in the activity of the studio; however, in 1971, upon the completion of the Paul VI Audience Hall (also known as Nervi Hall) in the Vatican, his presence in the office started to decline. Indeed, in 1972 Studio Nervi was led chiefly by his sons, Antonio and Mario.

Despite the many commissions, Nervi's two sons did not embrace progressive attitudes assumed by similar engineering firms, such as SOM in Chicago or ARUP in London. In fact, while these firms started using software for structural calculations while implementing a more advanced approach to structural design, Studio Nervi preferred to maintain avoidance of such modern specialisms (Poretti, 2017). This was evident in Studio Nervi's inability to provide any substantial advice in the overall structural design of the tower in the MLC Centre in Sydney, designed by Seidler in 1973. In fact, despite the early involvement of Studio Nervi in the project, the static problem of the tower was entirely solved by Australian engineers, with the consultancy of the American Portland Association and an engineer from SOM, Fazlur Kahn. Nevertheless, Seidler could rely on Antonio to discuss and refine the main structural elements of the tower and their architectural image. Eventually, like for Australia Square Tower, Studio Nervi provided the design profiles for the columns and beam-spandrels which – along with the lobby ceiling, an isostatic inspired slab – aesthetically enriched the monumental body of the octagonal skyscraper (Figures 4 and 5).

Along with the tower for the MLC Centre, Seidler requested Studio Nervi to design the cantilevering structures for the suspended plaza on King Street; the ceiling for the new restaurant; the lobby ceiling for the new Theatre Royal (1976) (Figure 6); and, subsequently the CTA building (1975) (Figure 7); which was added into the overall multifunctional centre plan, although belonging to a different client. Once again, Studio Nervi enhanced Seidler's pure geometrical solutions with the characteristic Nervi's crisscrossing ribbed patterns. Thus, the design for the restaurant and theatre lobby ceilings featured an unmistakable Nervi geometric rosette. Additionally, the suspended plaza and the CTA building were shaped as faceted, mushroom-like structures, reminiscent of the water tank reservoir for the Mirafiori factory, built in Turin in 1961. The design of these structures was particularly intricate and costly, which resulted, apart from in the case of the theater lobby ceiling, in simplification

Figure 5. MLC Tower – Lobby “Nervi” ceiling, 1979. © Penelope Seidler (photographer Max Dupain).

Figure 6. CTA building, 1980. © Penelope Seidler (photographer Max Dupain).

for these structures. The CTA building and suspended plaza were eventually redesigned by Studio Nervi with a simpler array of curvilinear ribs which still features the iconic sculptural stems of the two buildings, while the restaurant ceiling was simplified with a series of curvilinear beams (today demolished). In contrast, the theatre lobby ceiling was faithfully realized by following the original rich rosette designed by the Roman office which retraced the most classic Nervi’s ribbed pattern.

The MLC project, with its two ribbed slabs (tower and theatre lobby ceilings) and structural profiles of the columns and spandrels, further enriched the language of structural forms available to Seidler. Despite the suspicions expressed by the Australian engineers, who regularly questioned “why this way – is it for appearance only?” (Seidler 1977: HAS: Box 11). Seidler always passionately endorsed structural creativity and adopted the same philosophy in many other his own projects. For example, for the design proposal of the High Court of Australia (1972), Seidler promptly reused the first design option developed for the spandrel-beams of the MLC tower and even designed the courtroom with an isostatic-like ceiling. Although Nervi was not involved in the design, Seidler asked for his opinion on the proposal to understand if it would achieve a “reasonable expression”, with the intention of applying the “concept at a future occasion”. (Seidler 1973: PLN, MAXXI: P108/8). Nervi’s opinion was “very positive” as stated by Antonio’s letter: “the project creates that perfect synthesis between static and aesthetical aspect which, as you well know, is the basis of my father’s [Nervi] design philosophy” (Antonio Nervi 1973: HAS: Box 11). Eventually while the design for the High Court of Australia remained unbuilt, ten years later, at the Hong Kong Club building in Hong Kong, Seidler was finally able to build the beam with its original undulating upper flange as originally designed by Studio Nervi for the MLC tower. Even a constructive rational building like Grosvenor Place, Sydney (1992) is enriched at the ground level by an exposed concrete isostatic-like ceiling, similar in its structural logic and aesthetic to the one built at the MLC tower.

Figure 7. Sydney Theatre Royal – Lobby ceiling, 1976. © Penelope Seidler (photographer Max Dupain).

5.4 *The Australian embassy in Paris: Touching the ground*

In 1973, Seidler wrote Nervi thanking him for his assistance in securing the Australian Embassy in Paris (1973–1977) commission (Seidler 1973. HAS: Box 11) for which both Breuer and Nervi worked as a design consultant, making the Parisian project a “unique tribute to two of Seidler’s greatest influences” (Leslie 2018). For the Australian Embassy, Studio Nervi designed the so-called “Nervi Column” (Figure 8), which signals the entrance of the chancellery, as well as a series of *pilotis* that support the upper floors of the administrative office block (Figure 9). These elements belong to a long tradition of

Figure 8. Australian Embassy in Paris – “Nervi column”, 1978. © Penelope Seidler (photographer Max Dupain).

Figure 9. Australian Embassy in Paris – “Nervi pilotis”, 1979. © Penelope Seidler (photographer Max Dupain).

unique pillars designed by Nervi, shaped on the flow of forces.

Like Nervi, throughout his extensive career, Seidler also overcame the problem of connecting his buildings to the ground by use of creative structural elements. One of his first attempts at resolving this architectural challenge was through the use of a consistent structural shape, which can be found at the secondary building of Australia Square. Here, Seidler introduced a pillar with four branches supporting the upper levels. For the first time, design of the Australian Embassy gave Seidler, in conjunction with Studio Nervi, the opportunity to further explore this often difficult design aspect. After a few trials for the Chancery porte-cochere, the resulting design was an elegant fan-shape like column which features an opening that, following the intention of Studio Nervi, allows the natural lighting to illuminate the entrance behind while bringing down the weight imposed by the façade above. (Antonio Nervi 1973. PLN, MAXXI: P112).

While Seidler could collaborate with Studio Nervi to solve the design of the columns at the ground level of the embassy, in his other buildings he could only rely on Nervi legacy and vocabulary of forms developed during the 15-year collaboration. Only a few months after the opening of the embassy, Nervi died, a loss that, together with the untimely death of his son’s Antonio in the same year, led to the office’s closure.

Seidler continued to uphold the lessons of Nervi throughout his enduring career. Indeed, in his following buildings, such as the Grosvenor Place in Sydney and at the Riverside Centre in Brisbane, Seidler adopted a section for the pillar that recalls the trestle designed by Studio Nervi, for Seidler, for a bridge proposal in Brisbane (1978). And even Seidler’s last building, the Ian Thorpe Aquatic Centre in Sydney (2001–2007), features a series of pillars that for both structural form and function recalls Nervi’s pillar that supports the iconic vault of the Nervi Hall in the Vatican (1971).

6 CONCLUSIONS

Harry Seidler’s education under Marcel Breuer and Walter Gropius equipped him with a strong understanding of the functional and technological aspects behind architecture. To this, Nervi added a structural sensibility that, through a rich vocabulary of structural forms, enabled Seidler to create a strong dialogue between architecture and structural aesthetic. As a result, Seidler extensively showcased in Australia potentials and richness of structural expressionism in architecture.

In conclusion, while this paper has provided insight on the influence that the Nervi-Seidler collaboration had on Seidler’s work, it also elucidates the Australian chapter of Nervi’s “third life”, during which, through Studio Nervi, he explored his signature structural aesthetic – today known as Nervi Style – and that in Harry Seidler, Australia found its promoter and ambassador.

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History of Construction Cultures – Mascarenhas-Mateus & Paula Pires (eds)

The experiments on measurement models for the Munich Olympic site

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ABSTRACT: The Olympic site in Munich is distinguished by the lightweight cable nets of its symbolic roof construction, shaping the image and success of the “cheerful games” in 1972. The designing process of this emblematic structures was a challenge for civil engineering before the invention of high-performance computer technology. The realisation of this innovative cable nets required the cooperation of many different disciplines in civil engineering and was possible only through experiments with physical models. Of the many models used by the engineers in the 1970s, only a few have survived. The paper will describe the networks of actors in civil engineering participating in this innovative planning process and the essential role physical models played in the constructing of the lightweight cable nets for the Munich Olympic site.

1 INTRODUCTION

The ensemble of the Olympic Park in Munich is in the early stages of applying for the UNESCO World Heritage status. The most emblematic parts of this ensemble are the lightweight, transparent cable net constructions of the stadium, the sports hall, the swimming pool and the entrance areas. The designing process for these widespan lightweight structures of unprecedented dimensions was only possible with the help of experiments using physical models and the development of new measurement and calculation methods. Unfortunately, most of the models, which were produced for designing and dimensioning these cable net constructions are lost and to a large extent even forgotten. The application as a UNESCO World Heritage offers a good opportunity to focus on these hidden actors and to analyse the networks of engineers involved but seldom mentioned. Without their professional expertise the innovative construction could never be realised.

The large number of models that were built and tested reveals that physical models were of great importance for the designing process, the dimensioning and finally the construction of the Olympic roofs in Munich. The research question is to establish how the experiments on the physical models were carried out and contributed to the design and decision-making processes. This raises the question of the role of the network of actors – architects, civil and computational engineers, testing institutions and the Munich Building Administration – during the designing and building process. Which new methods did the interdisciplinary design team invent and apply in Munich, especially regarding the use of digital methods? It is thus interesting to study how new technological achievements in computational science in the 1960s and 1970s found their way into the working processes of architects and engineers.

2 THE ROOFS FOR THE OLYMPIC SITE

2.1 *The design competition*

The realisation of the lightweight construction for the roofing of the sports facilities in Munich brought together many different disciplines of engineering: highly renowned architects as well as engineers were involved in the design and implementation process (Boller & Schwartz 2020, 569). The competition design was developed in the architectural office Behnisch & Partner in Stuttgart by Günter Behnisch, Fritz Auer and Jürgen Joedicke. The jury chaired by the famous Karlsruhe architect Egon Eiermann, who designed the German Pavilion for the World Expo in Brussels in 1958, was convinced by the landscape architecture and the organic, lightweight roof construction, which was conveyed through drawings by Fritz Auer and a simple form-finding model (Tomlow 2016, 68).

The idea for this design competition for the construction of the sports facilities, built for the XX Summer Olympics in Munich in 1972, was a suspended cable net that encompassed all sports facilities as column-free as possible. This scheme led to a pretensioned cable net construction, offering a large variety of roof shapes accommodating the modelled terrain. Also of significance was that this construction type offered great transparency, which facilitated the transmission of the sporting events on television (Schlaich 1972, 368).

The architects’ design was based on analyses of existing Olympic sites, such as the Tokyo site designed

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by Kenzo Tange for the 1964 Summer Olympics, which was built on a landscape model made of sawdust. The Munich architects were also directly inspired by the lightweight cable net of the German Pavilion for the International Exhibition in Montreal in 1967, constructed by the Stuttgart architects, Rolf Gutbrod and Frei Otto, widely published in architectural and technical journals. For the Munich construction form-finding models, mainly at a scale of 1:200, women's stockings were used to simulate the shape of the roofing by tensioning and lifting it with wooden sticks (Möller 2015, 602).

The competition jury was impressed by this competition model of Behnisch & Partner. Despite the lack of specific information on the construction, the project won against 99 other entries (Bach 1975, 269). The competition met with great international interest, especially on the part of engineers: the Norwegian-American engineer, Fred Severud, was convinced by the design and the French structural specialist, René Sarger, offered his support in the project (Meissner & Möller 2015, 26). At the beginning of November 1967, the Stuttgart engineer, Fritz Leonhardt, the architect-engineer, Frei Otto, and the cable net specialist, Peter Stromeyer, gave supportive statements on the feasibility of the design at the request of Günter Behnisch. Frei Otto offered the help of the Institute for Lightweight Structures (IL) to further the project, and Fritz Leonhardt and Peter Stromeyer joined as consulting engineers.

At the end of November 1967, despite some critical international opinions, Fritz Leonhardt reaffirmed his opinion of the feasibility of the structure, based on his experience in Montreal. Therefore, in December 1967, Leonhardt, together with Hubert Rüsch and Georg Burkhardt, were commissioned by the Munich *Olympiabaugesellschaft* (Olympia Construction Company) with a report on the feasibility. Nevertheless, the three engineers expressed some critic on the project progressing. But after the participation of Frei Otto and the Munich engineering office, Kupfer und Gattnar, Fritz Leonhardt changed his mind and supported the feasibility of the tent construction.

In June 1968, after considering several detailed structural variants, the decision was taken to construct the point-supported, cable-stayed suspended roofs. The design process for the roofs could begin in cooperation of the architects and engineers Behnisch & Partner, Frei Otto, Leonhardt and Andrä, as well as the Swiss engineer, Heinz Isler, who worked on the substructure of the stadium. The project manager for engineering in the office of Leonhardt and Andrä (later Leonhardt, Andrä & Partners / LAP) was Jörg Schlaich. In his project team, Rudolf Bergmann was responsible for the stadium, Knut Gabriel for the sports hall, Ulrich Otto dealt with the swimming pool, Karl Kleinhanß with the connecting roofs and Günter Mayr was responsible for all questions regarding construction. In addition, Herbert Kupfer and Richard Schuller were commissioned to check the structural calculations (Spieker 2009, 118–22).

2.2 *The concept of the roofs*

For the stadium building, a canopy was needed for the west stand, which was created by nine saddle-shaped curved cable nets in a row. Due to the use of boundary cables for the individual cable nets, only a few connections between contiguous nets were required for supporting. Due to the tension in the nets, however, areas were created that were almost flat, meaning that high prestressing was needed to reduce deformations caused by gravity and wind loads. The nets were suspended from eight large masts.

The construction principle of the sports hall was similar: a central, saddle-shaped cable net was formed by a supporting structure with two curved areas on each side. The complex geometry gives an idea of the high pretensioning necessary to realise it. In addition to the two main masts, further supporting masts were planned.

The roofing of the swimming pool was created by a cable net construction with surfaces tensioned by masts, with lens-shaped cable loops and low points similar to the construction of the Montreal Pavilion. The structure opens up to the lake which was created for the Olympic landscape site. The smaller nets covering the surrounding areas and accesses, consist of differently designed cable nets attached to the main roofs or self-supported by their own masts (Schlaich 1972, 366–7).

3 MODEL TESTS

3.1 *Design and measuring models (Messmodelle)*

Due to the initial scepticism concerning the size of a construction never built before, the client, the Olympic Construction Company, commissioned the planning team to carry out model tests already in the early planning phase. The responsibility for the entire technical model building was given to Frei Otto and his Institute for Lightweight Structures. With the help of form-finding models, the geometry of the roofing was optimised. Witnesses involved repeatedly emphasised a significant communicative advantage of the models: everyone in the design team benefited from the models, as they enabled a simple and easily understandable representation of complex problems, which at that time could not be graphically represented (Tomlow 2016, 66). Using simple models made of polyester meshes at a scale of 1:200, the design was optimised in terms of landscape, architecture, geometry and construction by Frei Otto in close collaboration with the architects from the architectural office of Behnisch & Partner (Figure 1).

In this early planning phase, form-finding models were used to modify the design competition to avoid unnecessary moments and very high stresses. It was not possible to use simple mathematical methods to calculate the forces and tensions of the complexly shaped and statically indeterminate roof systems. It was therefore necessary, as for the implementation of

Figure 1. Design model at a scale of 1:200 (Bach 1975, 282).

the German Pavilion for the World Exhibition in Montreal in 1967, to carry out tests on measurement models to confirm the load-bearing capacity of the structures. These tests required different actors from specialised fields of civil engineering who were specialists in their respective fields.

For this method, called *Modellstatik* in German, further measurement models at a scale of 1:125 were produced – based on the form-finding models – at the Institute for Lightweight Structures by Frei Otto and his team. These so-called *Messmodelle* (measurement models), were made of nets of stainless, spring-steel wires (diameter 0.2 mm) with a mesh size of 24 mm (Bach 1975, 276–285). With a real mesh size of 75 cm, the net in the model corresponds to every fourth cable. Due to the size of the roofs and the scale given by the measuring table located in the IL pavilion in Stuttgart, the models were smaller than, for example, for the German Pavilion in Montreal, which led to a greater susceptibility to measurement inaccuracies (Meissner 2016, 51). For example, the boundary cables, which were made of copper wires (diameter 0.5–0.8 mm), had to be soldered at the nodes (Bach 1975, 285). Inaccuracies of a few millimetres could easily occur which, in reality, would mean several centimetres of deviation in the full-size structure. Further inaccuracies arose in the wooden and metal frames, which had to absorb the tensions of the masts, cables and foundations and were sometimes distorted (Tomlow 2016, 66).

The frame for the largest model – for the stadium roof – had a size of around 1.9 × 4.0 m and therefore had to be shifted on the measuring table during the experiments. The cable net of nine fields was supported by ten masts of different heights and a bundle of boundary cables. The masts in the model were between 34 cm and 61 cm high.

Figure 2. Measurement model of the sports hall at a scale of 1:125 (Bach 1975, 286).

The model frame for the sports hall measured 1.6 × 2.5 m and the roof itself was made out of a net with five fields and external masts of various heights, as well as under-tensioned so called “floating supports” (*Luftstützen*) inside (Figure 2).

The frame for the swimming pool model was 1.6 × 1.9 m. Designed in free shapes, the roof was supported by an external mast with a height of 64 cm in the model and a smaller mast, as well as low points inside the building.

For the roofs between the main sports venues, models were made in a model frame measuring 1.6 × 1.9 m (Bach 1975, 287).

More than 50,000 working hours were invested in the production and testing of these physical models during the project (Meissner 2016, 51).

3.2 *Measurement methods*

The scale of the measurement models resulted from the size of the measuring table (approx. 1.5 × 1.8 m) at the Institute for Lightweight Structures in Stuttgart. With the help of an advanced measurement technology, which was partly developed in the course of the design of the structure for the German Pavilion at the International Exhibition in Montreal in 1967, the tension in the models could be measured and thus the prestressing of the cable structures determined (Weber 2015, 574).

The forces generated under load in the individual cable nets could be determined with the so-called Montreal micrometre (Figure 3), a small gauge mounted at three points, developed specifically for?this purpose and, as a result of technical developments from the 1970s, with dial gauges. The geometry was recorded on the 3D measuring table using coordinates and nodes. The X, Y and Z coordinates were determined with a plumb line directly on the model, written down or saved on punched tape and transferred as a plan to a drawing device. The tensions in the model could be adjusted and changed with steel wire springs attached to the wire ends.

Figure 3. Montreal micrometres (Bach 1975, 289).

The principle of the above-mentioned measuring instruments which were developed at the IL, is based on the deflection of a wire under tension via a constant spring force. In some cases, special hooks were developed to place the instruments in the model more easily and with greater accuracy (Bach 1975, 276–290). The loads on the models were generated using steel blocks on chains. The blocks lay on a base plate, which could be raised and lowered pneumatically using car-tyre inner tubes.

Apart from Frei Otto's IL, other institutes of the Faculty of Civil Engineering in Stuttgart were consulted: The Institute for Model Statics (*Institut für Modellstatik* / IMS) under Robert K. Müller – one of the most important institutions in Germany specialising on model testing – developed strain gauges to measure the tension in the boundary cables under different load assumptions. In the context of this cooperation, experiments with the simultaneous application of several measuring methods were executed and continuously improved. The Institute for Applications of Geodesy in Civil Engineering (*Institut für angewandte Geometrie im Bauwesen*/IAGB) under Klaus Linkwitz was requested to use photogrammetry to measure the sensitive models and to generate cutting patterns for the roof cladding (Weber 2015, 574). The photogrammetric method used parallel light thrown onto the model by an optical bench, which allowed deformations to be recorded and measured with cameras (Weber 2012, 46).

In so-called multimedia tests, 18 Linhof cameras were used to take double exposure pictures and at the same time several miniature cameras recorded the mesh angles. Dial gauges and strain gauges were used to measure vertical displacement and tension (Figure 4). Through these sophisticated model tests and measurement techniques, the assumptions about the load-bearing capacity of the individual roofs under various loads could be confirmed and deformations could be anticipated (Addis 2021, 431–4).

3.3 *Hybrid model testing*

The development of the pretensioned cable net constructions was extremely complex; the geometry of the models was influenced by the prestressing, the mesh size, the alignment of the meshes, the type of the net boundary cables and the rigidity of the materials used for supports and foundations. The shape in the pretensioned state could not simply be created graphically but had to be generated through form-finding tests on models, which could then be used as a basis for static calculations. Therefore, the geometry of the form-finding models resulting from this process were measured and used as the basis for execution plans and to determine the cutting patterns for the roofing (Schlaich 1972, 369).

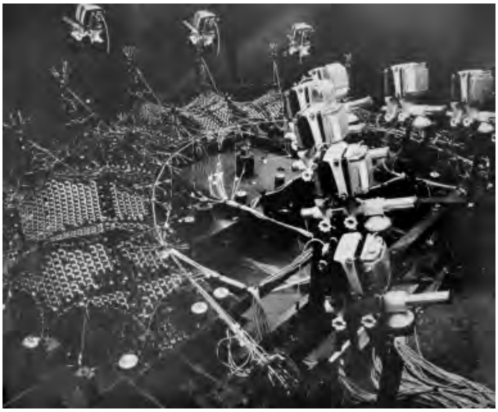

Figure 4. Multimedia experiments on the model of the stadium roof at a scale of 1:125 (Bach 1975, 292).

But some model tests failed because they were not accurate enough in areas with special curvatures. So, in the case of the stadium and the swimming pool, models at a larger scale (1:25) had to be built in order to improve the cutting accuracy, so that the measuring could be carried out geometrically by photogrammetry. In the case of the sports hall, optimisations on the models were tried, but without success. The complex geometry and, above all, the curvatures could not be sufficiently recorded and represented with the known measurement methods of the 1970s to generate the cutting patterns for the production of the roof cladding from the data obtained. The problem had to be solved in another way and, as a consequence, the interdisciplinary team was expanded: the IL (under Frei Otto) which was responsible for the measurement models and the IAGB (under Klaus Linkwitz) was supported by the Institute for Statics and Dynamics of Aerospace Engineering (under John Argyris), all located at the University of Stuttgart.

It is thanks to the interdisciplinary team that it was possible to digitally produce cutting patterns for the membranes of the roof claddings for the sports hall. The IAGB used the data from model tests to generate a digital model (Weber 2012, 49). These computer-based calculation methods were made using the first electronic mainframe computer at the University of Stuttgart (Möller 2015, 605). The data required for the mathematical calculation were derived from the photogrammetric surveys of the models (Bach 1975, 278). For the calculation, John Argyris and Klaus Linkwitz

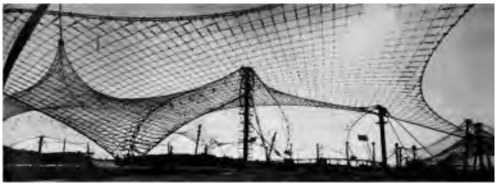

Figure 5. Pretensioned cable net construction of the roof of the swimming pool (Bach 1975, 253).

Figure 6. Test setup for simulating the uplift due to the wind (Bach 1975, 291).

introduced the new Finite Element Method. In this way, the cutting patterns for the execution plans could be displayed under pretension, considering the influences of materials and temperatures (Schlaich 1972, 372).

For the cable net construction, an extension of 1 mm per 75 cm mesh under pretension was calculated, so that the cables had to be made shorter than the final length to achieve the desired shape under pretension. The material properties of the cables, consisting of 19 galvanised wires, were considered in the calculations. In the executed construction, the cables were made in diameters of 12 mm and 16 mm and connected with aluminium clamps and held by bolts during the construction phase so that they could rotate relative to one another at the nodes (Figure 5). By tightening the screws in the nodes, the curvature of the roof surface was created by deforming the square meshes into rhombuses (Tomlow 2016, 65–66).

3.4 *Other models*

With the help of a further large number of models as well as a 1:1 prototype, materials and assembling techniques for the implementation of the roofs were planned and decided. Regarding aerodynamic loads, wind-tunnel tests, specially produced for this purpose, were carried out on models. These tests were carried out on both fixed and movable models in the wind tunnel and the results of these experiments were analysed by the engineers of Leonhardt and Andrä (Schlaich 1972, 373). A separate test (Figure 6) was developed for the roof of the swimming pool for which the uplift due to the wind could be simulated (Bach 1975, 291).

This was necessary as there was some criticism at international level regarding the aerodynamics of the roofs. The Swedish suspension roof specialist, David Jawerth, criticised the shape of the roof, despite a lack of information on the design process. He argued that the roof would be very prone to fluttering due to insufficient anticlastic curvature. The models were deployed to rebut these concerns. Finally, the measurements taken on the completed structure showed that the construction – as predicted by the model tests – had very little susceptibility to fluttering, largely due to the stiffening and damping effects of the acrylic roof cladding (Tomlow 2016, 65).

Since a shade-free roof skin was required for the television broadcasts of the games, a 1:1 mock-up test of around 30 x 30 m was built in Munich as a four-point cable network with the planned mesh size of 75 cm. Various roof coverings were tested on the prototype and the decision was taken to opt for transparent acrylic sheets, connected and made watertight using black pressed-in neoprene profiles developed by Frei Otto (Meissner 2016, 52).

Since the sports hall and the swimming pool are air-conditioned buildings, it was necessary to create an insulation layer underneath the cable net construction. For this reason, an insulating blanket consisting of a membrane made of polyester with PVC coating and insulation material welded into pockets was suspended under the net construction at intervals of between 0.5 m and 1.5 m. The form of the membrane was generated by measuring a wood-plaster model on the measuring table in the IL (Bach 1975, 299).

Other considerations and tests on large models were made for many details, including connections between the roof covering and the net, the form of the joints between the roof panels, the net and the boundary cable clamps and drainage systems (Bach 1975, 278).

From a production engineering perspective, the rediscovery and development of steel casting technology is noteworthy. This enabled many complex connections to be manufactured quickly and accurately.

In this context, vibrations tests were carried out for the cables used, which did not correspond to the standard-compliant radii of curvature, in order to obtain evidence of their safety. Many of the technologies used for the roofs in Munich were adapted and developed thanks to the Leonhardt and Andrä engineers' experience in constructing cable-stayed bridges (Spieker 2009, 124).

3.5 *The surviving models*

Unfortunately, only two of the many measurement models built for the Olympic roofs in Munich have survived. At the IL in Stuttgart, there is the 1:25 scale model of the low point T2 of the swimming pool (Figure 7) (Möller 2016, 1034). This is one of the larger-scale models that were built in order to improve the cutting accuracy in areas with special curvatures (Bach 1975, 278). The model is still on its original

Figure 7. Model of the low point T2 of the swimming pool at a scale of 1:25 (Bach 1975, 297).

rigid base made of marble. Unfortunately, this model shows signs of slight damage (Weber 2015, 574).

The second remaining model is on display in the visitor centre of the Olympic Park in Munich and is the 1:125 measurement model of the sports hall. The large model (approx. 2.0 x 1.5 m) was used as described above to carry out various tests, including the multimedia experiments. These two models are the last surviving witnesses of the extensive experiments on physical models used by the engineers during the construction of the Olympic roofs (Möller 2016, 1034). In their construction, they represent some kind of “knowledge stores” (*Wissensspeicher*) of the measurement models and their use in design the early 1970s.

4 CONCLUSION

The structural design of the Olympic roof in Munich was mainly due to a team of constructors and engineers from the Technical University of Stuttgart, who had already been working together successfully for several years and who were supported for the Munich project by additional specialists from the Stuttgart academic community. The technological innovations for pretensioned cable nets, which were achieved through the design, development and implementation of the roofs for the XX Olympic Summer Games in Munich were a milestone for civil engineering. The model tests carried out set new standards and constituted a research focus at the University of Stuttgart (Schlaich 1972, 368).

The hybrid method in using physical models in combination with new calculation methods with the help of digital technology were highly innovative. The multimedia experiments that were carried out brought the emerging digitisation forward and, thanks to newly acquired calculation methods, soon established the electronic process of designing complex geometries. The design and realisation of the Olympic roofs in Munich are thus also the beginning of the end of physical model tests in structural engineering. Even Frei Otto, who continued to work with physical models until the 21st century, described the new computer-aided processes, developed by the engineers around Argyris, Leonhardt and Linkwitz, as a unique scientific masterpiece (Spieker 2009, 122).

The new methods used for Munich were only possible with the unique interdisciplinary network of different participants in the project, involving engineers, architects, measurement laboratories and institutions for geodesy and computational mechanics, which furthered the development of new methods and processes in the long term. Despite initial tensions between some members of the design team, many of the participants later continued to work together in the collaborative research teams “SFB 64 Wide-Spanned Surface Structures” and “SFB 230 Natural Constructions” hosted at the Stuttgart Technical University in order to advance the development of lightweight structures (Tomlow 2016, 69).

The effort to get the Olympic Park adopted as a UNESCO World Heritage Site could highlight the success of the lightweight construction as architectural and engineering cultural heritage. It was only made possible through the use of measurement models and therefore these physical models should be considered as part of the engineering and cultural heritage from which we can still learn today. They require fresh evaluation in terms of their significance for the history of civil engineering in order to improve the consciousness of the public in general, but mainly of engineers to demonstrate their contribution to such innovative projects. To abandon these models would mean to devalue and to forget the importance of our technical achievements throughout history and to lose them as an inspiration and example for future research in engineering.

4.1 *Further research*

While the measurement models presented in this paper were produced and tested during the design of the Olympic site in Munich, similar measurement models were used for many other constructions in the course of the first half of the 20th century. Unfortunately, as in Munich, the majority of these measurement models have been destroyed or lost. For this reason, researchers at the University of Innsbruck, the Technical University of Munich and the University of applied Sciences at Karlsruhe have recently started a collaborative project to record the existing measurement models, to place them in their historical scientific and construction history context and to develop a concept for the long-term preservation of this technical cultural heritage. This project is funded by the German Research Foundation (*Deutsche Forschungsgemeinschaft* / DFG).

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History of Construction Cultures – Mascarenhas-Mateus & Paula Pires (eds)

The “3-dimensional wall” of the Centre Pompidou in Paris: Invention and evolution of a polyvalent device

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ABSTRACT: In the summer of 1971, Ove Arup & Partners and Piano+Rogers Architects presented to the French government what they called a “3-dimensional wall” as part of their project bid for the *Centre National d’Art et de Culture Georges Pompidou* in Paris. This would resolve structural and expressive questions and unite three elements in a spatial sequence. The architects imagined the 3-dimensional wall as a 3D sequence of screens that would create original and interactive effects. The engineers saw it as a structure that, described as “brut,” aspired to become a manifesto for a new metal structure in cast steel. Through recourse to a systematic analysis of published and unpublished sources and of interviews with the architects, engineers and administrators involved in the project, this paper reconstructs the evolution of the Centre Pompidou’s 3-dimensional wall from its initial conception to the gradual loss of its original layered structure.

1 THE ORIGINS OF THE 3-DIMENSIONAL WALL IN ROGERS AND PIANO’S RESEARCH

In the first half of January 1971, Ted Happold, senior engineer of the Structures 3 Division of Ove Arup & Partners, contacted Richard Rogers, a partner in Piano+Rogers Architects, to invite him to take part in the competition for the Centre Beaubourg in Paris, later known as the *Centre National d’Art et de Culture Georges Pompidou*.

Right from the initial stages of the project, Rogers and Piano set out to create a flexible and undivided space in which to house a variety of installations, from exhibitions of contemporary art and industrial design to a public library and areas for music, theatre and cinema. Piano and Rogers opted for very long truss spans that would leave the space free and be supported by a perimetric structure. This structure was broken down into a 3-dimensional lattice that assumed the forms of a space frame but would at once be transformed into a complex layered system that would be called a “3-dimensional wall.”

The origins of the 3-dimensional wall go back to considerations Rogers and Piano had formulated at the end of the sixties concerning the relationship between structure and envelope. Within the framework of the conceived prefabricated units called “general purpose shells,” Rogers regarded the envelope as an assembly of prefabricated panels of industrial origin to be used in a self-supporting function and, in large-scale projects, as an enclosure to create an envelope “freed [. . .] of the exposed steel structure” (Rogers 1966). In the context of his research into lightweight and modular roofing, Piano turned the space frame into an element that negated the façade and boxed in the space with 3-dimensional metal portals or frames, rendered waterproof by panels of concrete or reinforced polyesters.

Rogers’s interest in the envelope and Piano’s in accentuating the structure continued after the founding of Piano+Rogers Architects in the spring of 1971 with solutions that constituted the principles for the conception of the Centre Beaubourg. In the design of the ARAM Hospital Unit Piano+Rogers Architects considered and then discarded the idea of a reticular structural scheme with shells and technical equipment that anticipated the lattice of the Centre Beaubourg (Rogers & Young 1971). In contrast, for the building to house the Burrell art collection in Glasgow, the idea of effects of transparency was turned into a “total light box” made of panels produced by the OKALUX company. It consisted of a membrane of microscopic tubing inserted between two layers of glass which was able to provide insulation, filter natural light and be coupled with panels that created “optical” special effects. Testing a solution would be taken up again in the design of the Centre Beaubourg (Piano+Rogers Architects 1971).

2 THE INVENTION OF THE 3-DIMENSIONAL WALL: STRUCTURAL LATTICE, SUPPORT FOR PLANT AND INTERACTIVE ENVELOPE

The solutions for a structure and envelope similar to that tried in the ARAM unit and the Burrell Gallery found a synthesis in the project for the Centre Beaubourg in Paris early in the discussions held

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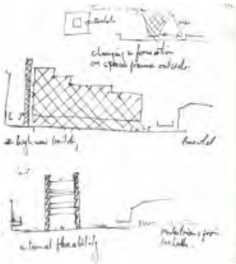
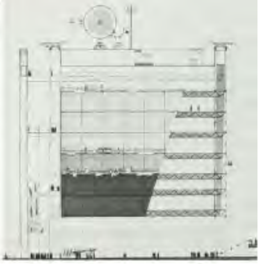




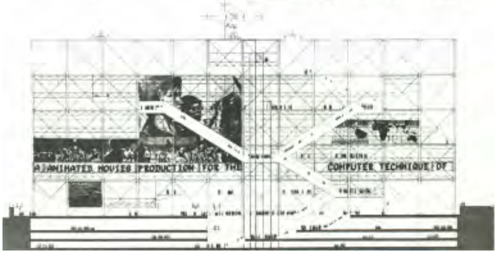


Figure 1 (top left). Richard Rogers, Centre Beaubourg, Preliminary sketches, spring 1971 (Hamzeian 2018). Figures 2 (top right) 3 (bottom). Piano+Rogers Architects and Ove Arup & Partners, Centre Beaubourg, Section and façade of the competition report, June 1971 (Renzo Piano Foundation, Genoa).

with the engineers of Structures 3 in the spring of 1971 (Rogers 1971). The idea of a system for delivering information and popular entertainment found expression in two vertical metal “space frames” with a rhomboidal mesh. They constituted the only support for a series of flexible platforms; they provided the anchorage of the vertical infill panels for the waterproofing of those platforms; and they acted as a support for the “slanting screen for information” that turned the space frame into a display that could be seen from the square planned for the front of the building, in line with a solution that Piano borrowed from his reading of the discussions about pioneering educational centres by Cedric Price, Carlo Pelliccia and Piero Sartogo in *Architectural Design* and *Casabella* (Figure 1 (top left)).

The space frame was developed further in structural terms in the competition report of June 1971 (Piano+Rogers Architects and Ove Arup & Partners 1971a). The two space frames were transformed into 3-dimensional lattices of vertical tubes and braces. The lattices were now 170 metres long and 51 metres high, subdivided into 12 bays measuring 12.80 metres each, and were stiffened by diagonal braces in the form of tie beams and horizontal braces in the form of beams. Set 48 metres apart from the other, each lattice was made up of two frames with a span of 3.20 metres consisting of tubes with a constant circular section. The support for the floor slabs was provided by light Warren trusses of 1.60 metres in height and was anchored to the tubes of the 3-dimensional wall by cast-steel elements called “special friction collars” (Figures 2 (top right) and 3 (bottom)).

The accentuation of the vertical structural elements at the expense of the homogeneous arrangement of the space frame resulted in terminological uncertainties. Piano and Rogers were aware that they were on the point of developing an unusual system that was no longer a traditional space frame nor a generic skeleton or framework, but was not a grid either as they wanted to keep the original structure of diagonal lines in their lattice. The terminological uncertainty that can be found in the competition report, where the words “grill” and “façade” appear, was resolved with the predominance of the term “3-dimensional wall,” which reactivated the idea of wall as this system re-created a layering of surfaces, obtained through the combination of “wall panels” available in opaque, translucent and reflective versions and semitransparent display screens. These screens diversified into LED ones used to provide information and large screens for the projection of pictures and videos, represented with an imagery that criticized the repression of the student protests in 1968, the arms race of the superpowers and alluded to the possibility of turning the Beaubourg into a centre for alternative information (Figure 3 (bottom)).

Various systems were inserted into the 3-dimensional wall: escalators and walkways to turn the flow of visitors into a spectacle for the crowd; an air conditioning plant located on Rue du Renard, a solution of which the architects had not yet discovered the aesthetic potentialities; and, finally, “temporary structures,” “robots” and “art works” whose nature would be specified in developing the project (Figure 2 (top right)).

Although the engineers and architects agreed on the general form of the 3-dimensional wall, the competition drawings reveal the emergence of two visions. In spite of the bulk of the systems being inserted into the 3-dimensional wall, Piano and Rogers wanted to make the Centre interact with its surroundings using reflection similar to that employed in the Burrell Gallery and to achieve this turned back to the OKALUX panel, which in the model was extended to the whole envelope (Figure 3 (bottom)). The accentuation of the envelope induced the architects to dematerialize other elements of the 3-dimensional wall, from the escalators and walkways, housed in futuristic glass shells, to the audiovisual screens, made semi-transparent to reveal both the reflective envelope behind and the air conditioning plant that could have held a dialogue with those screens, which would have made it visible here and there, but that the architects still hesitated to design.

While the architects tended to rarefy the 3-dimensional wall and reduce its lattice to a diagrammatic drawing, the engineers seemed intent on making that lattice the manifesto of a new kind of structure, and conceived its joints as pieces of cast steel to be mounted without coverings – in their “brut” state as they described it.

Happold and Rice excluded not only any kind of cladding, from insulating mineral wool to the spraying of plaster, but even the hypothesis of mounting fire barriers on the envelope as they would have gone against the idea of transparency pursued by Piano and Rogers. So Happold and Rice opted to fill the tubes of the 3-dimensional wall with water treated with a solution that had been tested in the USA Steel Building in Pittsburgh completed in 1970, and in an office building for the SNCF company designed by Erno Goldfinger and Pierre Forestier in Paris, and which Structures 3 was applying in the International Conference and Hotel Centre at Mecca at the time.

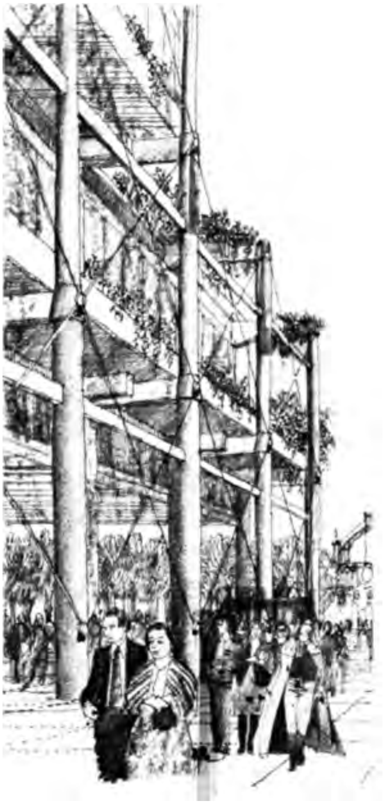
For the moment, the use of the aqueous solution kept together the visions that the architects and engineers were formulating for the 3-dimensional wall. In fact, it was the questioning of this fireproofing measure over the following months that would threaten the compatibility of the visions and cast doubt on the appearance of the building.

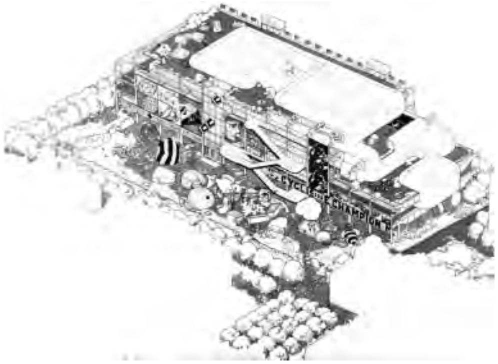
3 THE TRANSFIGURATION OF THE 3-DIMENSIONAL WALL

Having won the competition, the team contacted the *Délégation pour la Realisation du Centre Beaubourg* and drew up a preliminary plan, called the *Avant-projet Sommaire*. The need for trusses able to span the great length of the platforms induced the team to exclude the Warren truss proposed in the competition, rejected on the grounds of its paltry height, and resort instead to a pair of colossal Vierendeel trusses measuring 51x4.80 metres bound together by diagonal bars located at the end, in order to create a structural solution characterized by the alternation of “servant spaces” and “served spaces”—it was not just the terminology that alluded to the work of Louis Kahn.

The decision to solve the problem of the connection of the ends of the Vierendeel trusses by having them rest on a beam anchored to the two tubes by collars turned the 3-dimensional wall into a powerful trilithic structure. The tubes were divided into three sections by the progressive reduction in diameter so that to adapt to this tapering the collars assumed a conical profile. By this time, the 3-dimensional wall resembled a modern colonnade. The horizontal bracing and the crosses, which gave the structure its pattern of squares and diagonal lines, underwent variations: the former were moved downward to adapt to the level of the galleries and the floor slabs behind them, while the latter, considered redundant by the engineers, disappeared from most of the bays (Piano+Rogers Architects and Ove Arup & Partners 1971b) (Figures 4 (top) and 5 (bottom)).

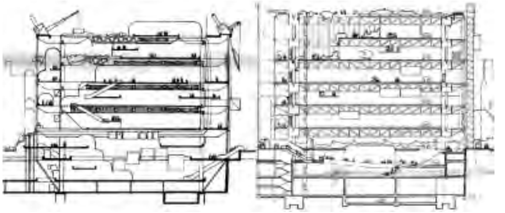
With the stiffening of the 3-dimensional wall, the envelope became independent, assuming rounded forms that reflected the animated topography of the technological turf laid in the square designed by Tony Dugdale, one of Archigram’s students who had been put in charge of the development of the project. The technical solution of that envelope would be sought in the industrial panel used in Rogers’ shells, which had already appeared in the competition design of the Centre, in the technical volume set on top of the building and now re-proposed in a translucent version over the whole envelope (Figure 5 (bottom)).





Figures 4 (top) and 5 (bottom). Piano+Rogers Architects and Ove Arup & Partners, Centre Beaubourg, Avant-projet Sommaire, detail of the 3-dimensional wall and aerial view of the building, October 1971 (Renzo Piano Foundation, Genoa).

However, the idea of a translucent envelope clashed with the technical problems posed by the system of filling the structure with water, which Arup’s engineer Turlogh O’Brien considered insufficient to ensure the two hours of resistance to fire required by the French building regulations. O’Brien proposed adding opaque fire barriers in the proximity of the structural lines of the 3-dimensional wall in a solution that would have laid an opaque grid over the envelope (O’Brien 1971).



Figures 6 (left) and 7 (right). Piano+Rogers Architects and Ove Arup & Partners, Centre Beaubourg, main section (on the left: Amended Design, March 1972; on the right: final Avant-projet Sommaire, May 1972) (Hamzeian 2018).

The audiovisual screens were reduced to a few LED panels located only at the front facing onto the square and derived from the infographic panels of NASA's Mission Control Center. In fact, these screens came into conflict with the vents of the air conditioning system that the plant engineers set all along the front onto Rue du Renard and with the cross bracing of the one facing onto the square.

The expressive forms of the envelope of the 3-dimensional wall were taken to an extreme between January and February of 1972, when the exorbitant costs of the Vierendeel structure and the loss of flexibility led the Délégation to reject the plan and request a second *Avant-Projet Sommaire* that would be presented in March, under the name of Amended Design. Lennart Grut, responsible for development of the structure, went back to Warren trusses on all the floors as proposed in the competition project, but now modified with the inclusion of the Gerber mechanism based on the division of the truss into three parts, a central beam resting on two cantilevered beams anchored to the inner tubes of the 3-dimensional wall and counterbalanced at the end by vertical tie beams anchored to the ground (Piano+Rogers Architects and Ove Arup & Partners 1972a) (Figure 6 (left)).

While the invention of the Gerber system brought the 3-dimensional wall back closer to the original design, the transformation of the outer row of tubes into tie beams and the recourse to a Warren truss of reduced height made the structure so light that it allowed all the elements of the lattice to assume unprecedented expressive forms that emphasized all the conduits, those of the visitors as well as those of the fluids, bestowing on the Centre the image of a fantastic oil refinery. The accentuation of these ducts also affected the layering of the 3-dimensional wall. The audiovisual system was reduced to signage displays facing onto the square to draw attention to the crowd moving around the building and screens facing onto the escalators to entertain visitors as they ascended. In the envelope at the rear, the sculptural profiles of the ducts broke the space into capsules, domes and shells that protruded from the platforms and invaded the 3-dimensional wall in a play of recesses and expansions derived from the plastic lines and rotundities of Archigram's pneumatic volumes and those of their students in the Chrysalis group, who from this point participated in the project (Figure 6 (left)).

The transformation of the structure and the attempt to come up with an envelope on organic lines further polarized the visions of the architects and engineers for the 3-dimensional wall. To keep these visions together Grut, along with Laurie Abbott and Philippe Robert, architects in the Piano+Rogers Architects team, went back to the drawing board with the design of the structural components, reworking the solutions for its fireproofing: they re-designed the cantilevered beam in the form of a shape cast of solid metal with a high latent heat, extending the system of filling with water to the central Warren truss, now hollow, and added an external cooling system based on spraying water onto the trusses (Abbott 1972).

4 TOWARD AN OPTICAL STRUCTURAL SYSTEM

With its spaces made up of recesses and expansions and its organic envelope, the Amended Design of March 1972 betrayed the fundamental principles of the design. And so, Rogers, in the process of drawing up the new *Avant-projet Sommaire* to be submitted to the Délégation in the summer, decided to bring it back to its origins by reinstating the flexible space and the audiovisual screens.

The re-founding of the project took place against the background of the temporary abandonment of the Gerber system of trussing in favour of a Warren truss with a height of three metres anchored to the tubes by a box joint and extended into the gallery by means of a reticular bracket. The 3-dimensional wall once again took on the form of a 3-dimensional frame with a checked pattern and diagonal lines but maintained the differentiation of the vertical elements with external tubes of reduced diameter that, having lost the role of tie beams, became a redundant bracing retained to preserve the image of the 3-dimensional lattice (Piano+Rogers Architects and Ove Arup & Partners 1972b) (Figure 7 (right)).

The envelope again assumed a configuration with sharp edges, but the setback of 1.50 metres from the axis of the tubes created a novel hierarchy. The envelope was turned into a screening to be aligned with the joint of the trussing of the floor slab. The setback should also be seen in the light of the discussions over the fireproofing of the structure that Arup's engineers were now carrying out with the Heat Transfer and Fluid Flow Advisory Unit of the Atomic Energy Research Establishment at Harwell. The setback distanced the 3-dimensional wall from the interior of the building, where the fire might originate, and consequently reduced the risk of collapse of the lattice resulting from an excessive rise in temperature.

However, the transparency of the envelope was subject to yet another revision. The joint between the tube and the truss with its imposing block of asbestos housed in a cube of metal created a discontinuity in the translucent screening of the building. The panels lost their mirror finish as their role now became simply one of closure and backdrop for a translucent audiovisual envelope that was reintroduced to become the project's true protagonist. In addition to the translucent screens, Rogers enriched the 3-dimensional wall with optical devices. While it had precedent in the panels of the Burrell Gallery, the idea of this artistic layering reflected President Georges Pompidou's passion for contemporary art and his idea of turning the Centre into a total work of art. Proof of this is the proposal, made in the fall of 1971, to have a *coloriste* work alongside Piano and Rogers, a figure to be chosen from among artists like Yaacov Agam, Victor Vasarely and Carlos Cruz-Diez (Domerg 1972a). It was from the work of these artists that the artistic envelope took its inspiration. The geometric pattern of concentric circles on the semi-transparent panel measuring around 40 metres on a side that appeared in the spring seems to have been an echo of the façade of the RTS building designed by Vasarely. In the solution produced in the summer the architects collaborated with the artist François Morellet on the colours to be applied to the air conditioning systems contained in the 3-dimensional wall that were to become the key element of the front onto Rue du Renard. In the solution dating from the winter, finally, between luminous newspapers, audiovisual screens, laser displays and machines for the production of artificial mist first tried out by Chrysalis in the Pepsi Pavilion, the 3-dimensional wall was fitted with panels for the creation of "mirages" and other translucent panels able to create optical effects by interacting with the technical plant behind them (Piano+Rogers Architects and Ove Arup & Partners 1972c). This solution, not so distant from the idea of an interactive and constantly changing optical screen that Agam had proposed to Pompidou for the Centre in the fall of 1971, gave a complete new hierarchy to the 3-dimensional wall, where for the architects the metal lattice and the infill panels behind it now had the role of support and backdrop respectively (Domerg 1972b).

5 ACCENTUATION OF THE STRUCTURE

Between the end of the spring and the winter of 1972 the idea of a 3-dimensional wall consisting of screens and ducts with artistic pretensions was undermined by the criticisms of the Délégation and the Élysée and by an unprecedented accentuation of the structure advocated by Arup's engineers. From Robert Bordaz, chair of the Délégation, to François Lombard, director of the Centre's planning team and to Pompidou himself and the minister of the economy and finance Valéry Giscard d'Estaing, the main players involved in the realization of the project criticized the accentuated *technologism* of the design and, when the definitive budget for the work was drawn up, downgraded the audiovisual system to the status of a piece of equipment that could be installed once the building had been completed.

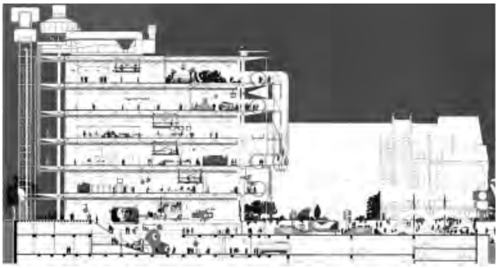


Figure 8. Piano+Rogers Architects and Ove Arup & Partners, Centre Beaubourg, Final Design, main section, Spring 1973 (Renzo Piano Foundation, Genoa).

The abandonment of the screens occurred against the background of a decisive passage in the evolution of the structure, which in the summer of 1972 returned to the tripartite Gerber truss, reworked by turning the cantilevered beam, from this point on dubbed the "gerberette," into a solid structural shape anchored to the internal post in an eccentric position with respect to its barycentre (at 1.50m from its inner end), so as to make the joint connecting it to the Warren truss coincide with the line of the envelope, still set back from the 3-dimensional wall. Rice and Grut sought to give the gerberette a sculptural profile that would reflect the potentialities of the cast-steel technique. The engineers now set out to enhance the plastic expressiveness of the 3-dimensional wall, emphasizing the mechanics of the joints and the metallic finish. Bordaz and Domerg, under pressure from Rice and Grut, were persuaded that the appearance and success of the entire Centre Beaubourg would follow from the design of those cast joints (Figure 8).

Arup's engineers started to focus on the fireproofing again in search of "other measures" that would make it possible "to leave the external steelworks totally unprotected" (Pearson 1972). For the tubes, the hypothesis of filling with concrete was assessed and studies of the system of using water continued with the advice of L.G. Seigel, an engineer from the Applied Research Laboratory of the United States Steel Corporation and one of the leading experts on the protection of metal structures by this method. For the gerberette the engineers went back to the hypothesis of placing a cube of intumescent material around the joint of connection with the Warren truss in line with the envelope, but they now also combined it with the insertion of an opaque panel as a fire barrier at that point. In doing so they showed that to ensure the "brut" finish of the structure they were ready to dispense with the translucent envelope imagined by the architects.

6 DISAPPEARANCE OF THE AUDIOVISUAL SCREENS

In the fall of 1972, the architects were once again convinced that the image of the Centre Beaubourg depended on an envelope capable of interacting with the technical plant, whose aesthetic and decorative value was now consciously pursued. The reluctance to renounce this image was reflected in the detailed study of the Centre, known as the *Avant-projet Detaillé,* presented in December 1972. In the dossier, the most recent and complex version of the audiovisual envelope was described, based on optical panels, lasers and fog machines. In the technical drawings, however, the audiovisual envelope had disappeared and emphasis was placed instead on the structure, the plant, whose complex design was still being worked on, and finally the envelope. Based on a modular panel with a height of seven metres and a width of 1.60, and made of an as yet unspecified material, this ceased to be a backdrop and again played a part in the appearance of the 3-dimensional wall. Despite the attempts of the architects to propose it again in scaled-down versions, ranging from a traditional projection system designed in collaboration with Ford Industries to an audiovisual spectacle conceived by the composer and architect Iannis Xenakis, the audiovisual screens were abandoned when Bordaz and Ove Arup met in January 1973. By this time Bordaz had been persuaded to realize nothing more than the wiring system for a hypothetical installation of the audiovisual screens before the opening of the building and to bet on the cast structure conceived by Rice and Grut. It was as suggested by Ove Arup: "this structure is the architecture" (Ahm 1973; Arup 1973).

The accentuation of the structure in the spring of 1973 was so deeply rooted in the minds of the engineers and the client that the transparency of the envelope was again brought into question. The fire barriers which were to be installed along the vertical lines of the structure were now positioned in the vicinity of the fire escapes and in the upper part of each panel, i.e. in the area close to the metal trussing of the floor slabs affected by the passage of the ducts and the gerberette, in a solution that laid a heavy and opaque grid over the envelope, turning it into a wall with windows (Grut 1972).

7 FIRE REGULATIONS AND STRUCTURE VERSUS TRANSPARENCY

The disappearance of the audiovisual system and the undermining of the envelope's transparency convinced Piano and Rogers to follow the recommendations of the fireproofing dossier and entrust its fine tuning to Robert and then to Claude Gallot, assisted by Eric Holt, Mike Davies and the Arup engineers Robert Pearson and Alan Denney. Rogers proposed applying to all the panels of the façade, including the opaque fire barriers, a sheet of special glass with particular effects of reflection that would bring back into play, at least during the daytime, the idea of a reflective envelope that had been part of the competition proposal (Davies 1973).

Both the interdepartmental body charged with analyzing the fireproofing measures of the Centre Beaubourg, the *Groupe Restreint du Comité de Classification des Eléments de Construction,* and Seigel, who in this phase was tackling the question of the fireproofing in an integrated manner, called for a drastic reduction in the size of the panels, something that would have meant the appearance of a new opaque grid over the envelope, that of the frames of its panels.

To get rid of this grid Rogers went for sophisticated solutions contained in the dossier for the call for tenders for the construction of lot 7, "façade": a reflective panel with no frame ("frameless glass") to be fastened to the façade with "spring clip holdings" located at the corners which Norman Foster was developing in those months for the headquarters of Willis Faber & Dumas. To reduce the risk of breakage in a fire Rogers envisaged fitting the panels with a system for spraying them with water similar to that suggested for the gerberette (Young 1973).

The only French companies to put in bids, SEAL, CSB and CFEM, submitted exorbitant estimates and as a result the call for tenders was declared unsuccessful and the design of the envelope and related fireproofing systems was again called into question (EPCB 1973). Rogers went back to a traditional frame but to ensure that the panels would be as large as possible and to overcome the reservations that *Groupe Restreint* had expressed with regard to the system of filling with water, proposed coating the structure of the 3-dimensional wall with a special protective paint (Gallot 1973). This solution had been ruled out in the fall of 1971 owing to the lack of certification and fear of a progressive loss of effectiveness caused by weathering. In summer 1972 it had been considered again, but only for the trusses inside the building with the hypothesis of using, first, the intumescent paint Citex 89 produced by the American firm ALBI, soon rejected owing to the great thickness required to achieve a resistance of two hours, and then the Thermo-Lag subliming paint of the American TSI company, used on satellites and space rockets, that only needed a coating of 5mm (Robert 1973). The thinness of the coat of Thermo-Lag represented the best compromise for the engineers since, while requiring renunciation of the appearance of a metallic surface for the 3-dimensional wall, it made it possible to emphasize the plastic lines of the structural shapes and cast joints.

The use of paint on the entire structure of the Centre induced Rogers and Piano to look at the question of colour, which, originally envisaged to make the technical installations stand out, was now extended to all the elements of the 3-dimensional wall. Together with Morellet, the architects came up with a functional colour code based on a pop palette. Red and blue were chosen for the ducts of the air conditioning system, orange for the wiring system and green for the plumbing; for the structure, finally, after versions in silver and then tomato red, they settled on bright yellow (Rogers 1974).

The compromise of a 3-dimensional wall defined by a translucent envelope, a structure with original nodes and a coating of paint extended to all its elements was

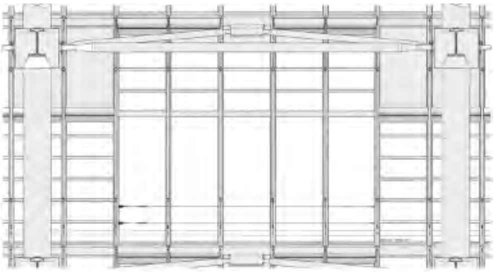


Figure 9. Piano+Rogers Architects and Ove Arup & Partners, Centre Beaubourg, Final Design, Facade detail (with opaque members in grey), 1977 (Renzo Piano Foundation, Genoa).

thrown into crisis in the summer of 1973. On the one hand the fire that broke out on 2 August at the Summerland leisure centre in Douglas, on the Isle of Man, making headlines in part for the inadequacy of the fireproofing, convinced the authorities in Paris to tighten the standards of fire protection required for the Centre Beaubourg. On the other, Arup's engineers rejected the use of Thermo-Lag, regarding the test pieces sent from America as inadequate and accusing TSI of not yet having finalized the agreement with a French distributor (Flash 1973).

The replacement of Thermo-Lag with a traditional paint saved the colouring of the 3-dimensional wall, but not the envelope behind it, where the necessity arose once again of protecting the structural lattice against the risk of fire. This time its transparency was preserved by Seigel who, in an updated version of his fireproofing dossier, declared that it was possible to return to the idea of a totally transparent envelope on condition of a reduction in the "fire load" of the building through the use of non-flammable furnishings, reinforcement of the profile of the horizontal bracing and replacement of the opaque fire barriers with translucent fire-resistant panels of wired glass, able to resist fire for two hours (O'Brien 1973). Notwithstanding the discordant views of the consultants contacted in the summer – positive those of the Saint Gobain corporation and negative those of the British Fire Research Station – and some second thoughts on the part of Seigel himself, the architects revised the dossier for the call for tenders of "lot 7: façade" with the fire-resistant translucent version and carried out two tests at the *Centre Scientifique Technique du Bâtiment* (CSTB) on two panels with a double layer of wired glass that had different frames: one of concrete and the other of metal.

With the failure of the second test (in which the inner panel collapsed after about one hour), the idea of a totally translucent envelope was in crisis, but ultimately partially preserved due to an important reduction in the dimension of the glass panels and the introduction of fireproofing steel louvres, and an external cooling system based on spraying water onto the glass. These improvements were applied in the version that would actually be constructed. For the front onto Rue du Renard an opaque envelope was used that was composed of white concrete panels with no glazing, while on the front facing the square the same panels were used in the vicinity of the gerberettes, along with glass panels set in thick metal frames and reinforced by reticular bars at right angles to the envelope (Figures 9 and 10).

Figure 10. Piano+Rogers Architects and Ove Arup & Partners, Centre Beaubourg, Final Design, Rue du Renard Façade, December 1973- Spring 1974 (Renzo Piano Foundation, Genoa).

8 COLOR AS THE LAST VESTIGE OF AN ARTISTIC ENVELOPE

After the suppression of the information screens and the translucent envelope that constituted the original layering of the 3-dimensional wall, the artistic effects that had been studied in collaboration with the principal exponents of avant-garde op art lost their dynamism and were reduced to a painted facing. In December 1973 the Delegation, now called the *Établissement Public du Centre Beaubourg* and supported by Pompidou, rejected the pop palette, replacing it with a version in shades of blue and brown that Pompidou derived from paintings by Georges Braque (Pompidou 1974). A few months later François Mathey and Pontus Hultén, directors respectively of the C*entre de Création Industriel* and the *Musée des Arts Plastiques*, both housed in the Centre, were also persuaded that the pop palette was incompatible with the idea of using the 3-dimensional wall as a support for artworks and proposed painting the structure in neutral tones: silver and ultramarine or "brun tour Eiffel" (EPCB 1974). The debate over the question of colour grew heated in the summer of 1974 when Giscard d'Estaing, Pompidou's successor as president of the French Republic, tried to scale down the whole project. Dithering over the pop palette obliged the architects first to delay the painting of the structure in the factory, then to use grey paint for the first coat and, finally, to apply the last coat directly on site, in white. In this way the artistic expressiveness of the 3-dimensional wall was reduced to the colours of the technical installations which, in spite of minor variations for the elevators, hoists and the air vents on the ground, were painted in a functional palette of pop shades.

By the time the building was opened under the name of the *Centre National d'Art et de Culture* by Georges Pompidou on 1 February 1977, the spatial system of the 3-dimensional wall had been radically altered with respect to the original idea, as a consequence both of the technological limits of the day and the budget cuts made by the French Government, and of Arup's desire to turn that lattice into a new kind of structural organism with original joints made of cast steel. It was toward this idea that the engineers had constantly pushed the project in the face of all the challenges posed by the fire regulations. In the end, they succeeded in preserving its plastic expressiveness but not its metallic nature, hidden beneath the white paint. Of the interactive and artistic layering of the 3-dimensional wall, all that remained were the pop colours of the plant, vestiges of a machine that was supposed to have been an alternative device set down in the heart of Paris to provide information on everything, from the living flow of the crowd of visitors moving inside it to events taking place in every corner of the globe. What was left was a splendid metal skeleton whose empty interior was still available as a support for works of art.

ABBREVIATIONS

RSHP: Rogers Stirk Harbour and Partners-RSHP Archives, London
AN: Archives Nationales, Pierrefitte Sur-Seine, Paris
AA: Arup Archives, London
C: Collection
F: Folder
P: Project

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ABSTRACT: Most of Poland’s medieval roof constructions have been preserved in Toruń, prompting the authors to attempt to characterise medieval construction timber in Toruń. The following questions were asked: Where did the building material come from? What types of wood were used? How was the building material transported? What sections and tools were used? The research shows that the material came from the nearby forests and from remote areas from which it was transported by rafts to Toruń. It was pine and oak wood. A whole tree, half-tree, cross-tree, and sixth of a tree were used as building materials. A whole tree was pre-treated with an axe and then smoothed out with a carpenter’s hatchet. A half-tree, cross-tree, and sixths of a tree were obtained by sawing the whole tree. The research made it possible to characterise the medieval construction timber in Toruń.

1 INTRODUCTION

Toruń is a medium-sized city located in northern Poland. It was founded by the Teutonic Order in 1233. Before the end of the 13th century, the city’s layout was formed, consisting of three independent parts, adjacent to the largest Polish river, the Vistula, from the south. The first and most important member of this group is the Old Town with the parish church of St John. It was inhabited by a wealthy patriciate, dealing mainly with trade. The second is the New Town with the parish church of St James. The town was mainly inhabited by craftsmen. Between them there was a Teutonic castle. (Figure 1).

The town did not suffer much during any of the wars. As a result, its plan, the complex of church buildings and, above all, of burgher houses, remain unchanged to this day. Therefore, in 1997, it was entered on the UNESCO World Heritage List. Of course, not only the brick structures of the town have been preserved, but also largely wooden structures, mainly of the parish churches of St John and St James, and bourgeois buildings, i.e. burgher houses, outbuildings, and granaries, have been preserved. Despite this rich resource, only individual structures have been researched so far, mainly in the typological aspect. Wood, however, the construction material itself, has not been given much attention.

This desideratum prompted the authors to try to characterise wood as a material for the construction of medieval roof structures and other wooden structures in Toruń. The following pivotal questions were asked: Where did the building material come from? What types of wood were used? How was the building material transported to Toruń? What sections were used? What tools were these sections obtained with?

Figure 1. Plan of Toruń, UNESCO World Heritage List application. The structure from the Middle Ages. A. Old Town; B. New Town; C. Teutonic castle; 1. Church of St John; 2. Church of St James; 3. burgher house, 12 Św. Ducha St.; 4. burgher house, 15 Kopernika St.; 5. burgher house, 2 Mostowa St.; 6. burgher house, 6 Mostowa St.; 8, burgher house, 9 Panny Marii St.; 8. burgher house, 13 Rabiańska St.; 9. burgher house, 20 Rynek Staromiejski; 10. burgher house, 11 Wielkie Garbary St.; 11. burgher house, 7 Żeglarska St.; 12. burgher house, 10 Żeglarska Street.

An attempt was made to find the answers to these research questions by analysing the existing substance of selected structures from the Old and New Towns of Toruń. Comprehensive historical and architectural studies were carried out for them, which were then supplemented with dendrochronological studies. The results of these studies are presented below.

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Middle Ages until the end of the 18th century in the light of interdisciplinary research on roof structures".

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2 THE ORIGIN OF CONSTRUCTION TIMBER

The issue of the origin of the construction timber used for the construction of wooden structures in medieval Toruń is an aspect that has practically not been addressed in previous studies. The traces of rafting, which were discovered on many elements of both the frame and roof structures, indicate that the wood was harvested from forests located farther away from, or closer to, the city and transported by rafts to Toruń.

More on this subject can be said in relation to the roof structures of the Old Town parish church of St John. The present form of the church is the result of many transformations taking place from the end of the 13th to the end of the 15th century. The dendrochronological research shows that oak wood was used in the second decade of the 14th century to build the roof structure over the central nave. It partially came from the vicinity of Toruń (Ważny 2014). On the other hand, some of the pine rafters, used at the same time to roof the aisles of the church, came from Dobrzyń Land (Ważny 2017), located about 65 km east of the city (Figure 2).

The structural elements used in the second decade of the 15th century in the roof structure over the north adjoining annexe were brought to Toruń from various areas, i.e. the vicinity of Toruń, Dobrzyń Land, and the Lower Vistula area, about 65 km north of Toruń. Most surprising are the results of the study of the oak entablature under the belfry structure from the mid-15th century: one beam comes from the area of Pułtusk, a town about 200 km from Toruń, and the other one from the Podlasie region (Ważny 2017), about 350 km to the east of Toruń.

Figure 2. Map of Poland, Toruń and places of origin of the building material: 1. Dobrzyń Land; 2. Lower Vistula; 3. Warmia; 4. Podlasie; 5. Pułtusk.

For the construction of the roof structure over the burgher house at 6 Mostowa St. in the mid-16th century, timber from Warmia was used, at least partially, which was transported along the Drwęca River to Toruń (Ważny 2015), just like the building material for the church.

3 TYPES OF WOOD USED FOR CONSTRUCTION OF ROOF STRUCTURES

Information on the types of wood used in the medieval timber structures in Toruń is primarily the result of dendrochronological research. The research suggests that only two types of wood were used, i.e. oak and pine.

Built above the chancel of the parish church of the Old Town at the beginning of the 14th century, the rafters of the roof structure over the central nave were made of oak, as well as the timber wall plates and tie beams in the roof structure (Ważny 2014, 2019). Both roof structures are heavily layered. The results of architectural studies carried out by the authors of this article (Schaaf & Prarat 2015) or under their supervision (Mrowińska & Pytlik 2019), and dendrochronological studies, make it possible to draw the conclusion that the roof structures were originally made entirely of oak.

In addition, oak was used in this church to make the entablature of the tower on which the main belfry structure rests (Ważny 2017; Zielski 2001), as well as used for the belfry structure, made in the mid-15th century (Okon 2002). In the bourgeois architecture, the use of oak wood was found only in the case of the entablatures over the basements in two burgher houses: at 20 Rynek Staromiejski St. from 1375 (d) (Konieczny 2007c), and at 2 Mostowa St. from 1546–47 (d) (Ważny 2015).

The research carried out so far suggests that oak was used very rarely and only to make the main structural units. This is shown not only by the few examples mentioned above, but also by another fact. In the parish church, wooden structures with a smaller span or less load were made of pine, not oak.

This is evidenced by numerous research monographs prepared as part of student exercises under the supervision of the authors and then dendrochronological studies of the roof structures over the aisles, roof structures over the annexes at the tower, and additional belfry structures. In the roof structure above the north aisle, there are pine rafters, either from the beginning of the 14th or the beginning of the 15th century (Chrzanowska & Wiśniewska 2018; Mańkowska & Tuliszewska 2018; Rokicka & Popławska 2018; Ważny 2017), in the truss above the north annexe at the tower – rafters and down braces made of pine wood from the mid-14th and early-15th centuries (Ważny 2017; Zielski 2001), and in the roof structure above the chancel – pine collars from the turn of the 1470s (Mrowińska & Pytlik 2018; Ważny 2019).

Previous studies have already shown that the joists and entablatures in the tower from the second half of the 14th century and from the 1470s, not loaded with a belfry structure, were also made of pine (Okon 2002; Zielski 2001). In the 1360s, also in St James's Church (the parish church of the New Town), the roof structure over the central nave was made despite the considerable span and, at the beginning of the 16th century, the roof structure over the southern aisle was made of only pine wood (Konieczny 2009). In the case of roof constructions over burgher houses, only pine wood was used in the period from the 14th century to the 16th century. Examples include the roof constructions at 10 Żeglarska St. from 1349–50 (d) (Konieczny 2007b) and at 2 Mostowa St. from the end of the 16th century (Ważny & Gmińska-Nowak 2016).

4 TRANSPORT OF WOODEN BUILDING MATERIALS

During the architectural research, traces of the transport of wooden building material by rafts have been found on many elements of medieval wooden structures in Toruń.

These are usually traces in the form of two round and often conical holes with an outer diameter of about 4 cm and a depth of about 10 cm (Figure 3) Moreover, in many openings, there are fragments of wedges and plated bands (Figure 4) These openings are spaced approximately 15–20 cm apart in the longitudinal direction of the building material (Figure 5), and provide evidence of the so-called "*verkeilte Wiedenbindung*", discussed and illustrated in a number of studies (Figure 6).

The Toruń research shows that wood for the construction of the frame structures at 11 Wielkie Garbary St. from the end of the 13th century and at

Figure 3. Toruń, parish church of St John, belfry structure, mid-15th century, a round and conical hole in cross-section opening attesting to the rafting of wood.

Figure 4. Toruń, parish church of St John, the roof structure over the north aisle, an opening in which there is a wedge and plated bands, which attests to the rafting of wood.

Figure 5. Toruń, 9 Marii Panny St., a bolt of the building frame with two openings, with a wedge and a tree twine in one, attesting to the rafting of wood.

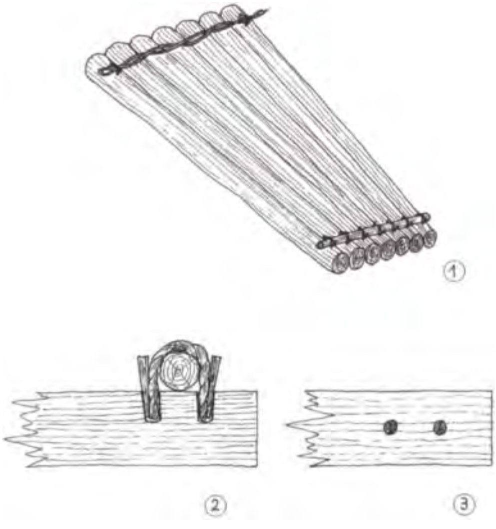

Figure 6. Building a raft, cf. Fischer-Kohnert, 1999.

Figure 7. Toruń, parish church of St John, roof structure over the chancel, only a single opening attesting to the tying of the logs with one wedge.

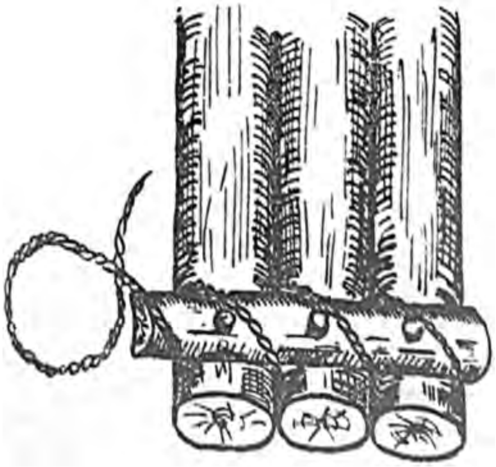

Figure 8. Tying with one wedge, with the arm wrapped with a rope.

9 Marii Panny St. from the turn of the 16th century, was transported in this way.

In the roof structures over churches, such a way of transporting wooden building material was proved in the parish church of St John over the chancel from the first years of the 14th century, over the main nave from the second decade of the 14th century (Schaaf & Prarat 2015), over the aisles from the second half of the 15th century (Chrzanowska & Wiśniewska 2018; Mańkowska & Tuliszewska 2018; Rokicka & Popławska 2018), and in the belfry structure from the second half of the 1440s, as well as in St James's above the chancel from the second decade of the 14th century, over the central nave from the 1360s, and over the south aisle from the beginning of the 16th century.

In some elements of the above-mentioned building frames and roof structures, two double openings or even more openings with the remains of wedges and plated bands in all openings were noted. They suggest that during transport it was necessary to repair the raft, or to temporarily store the locks and, therefore, to dismantle and rebuild the raft.

Figure 9. Tying with one wedge with a loop, cf. Eißing 2009.

In only one case, namely in the roof structure above the church chancel, only single openings were found in some elements (Figure 7), which prove another way of tying the logs to the raft, namely with one wedge, which either passed through the arm which was wrapped with a rope (Figure 8), or was directly wrapped with a plated band (Figure 9).

5 CROSS-SECTIONS OF CONSTRUCTION TIMBER

Architectural research has shown that different sections of wooden building material, which depended on the function of a given type of element in the roof structure, were used in the medieval roof structures of Toruń. This building material can be generally divided into three main groups: thick, medium, and thin building material. However, the cross-sections and processing within these groups are not rigid, but are partially subject to significant fluctuations, and it is not always possible to assign all elements to these three groups. These conclusions will be presented below using the example of two well-preserved roof structures, one from ecclesiastical architecture, the other from bourgeois architecture.

In the king strut structure above the south aisle of St John's Church from the 1440s, the thick building material includes tie beams, king struts, and sill plates of the longitudinal stiffening made entirely of whole trees. The cross-sections of these elements vary from 21–24 × 22–27 cm. The average building material is represented by longitudinal stiffening rails, which are also processed from whole trees. Their cross-section ranges from 18–21 × 20–21 cm. Thin building material includes passing braces in full roof structures and in a longitudinal arrangement, as well as collars in all roof structures, which are made of either a half-tree, or a cross-tree, or a sixth of a tree. The cross-sections most common among them include 15–18 × 18–21 cm. On the other hand, among the rafters and down braces, there is a great variety in both processing and dimensions, which made it impossible to assign them to

Figure 10. Torun, parish church of St John, roof structure over the south aisle, rafter with traces of transverse cuts attesting to the initial treatment with an axe.

one specific group of building materials. To be precise, they are made partly of a whole tree, partly of a half-tree, and partly of a quarter-tree, and their cross-sections range from approx. 25 × 30 cm to only approx. 18 × 19 cm (Kasoń 2018).

In the collar beam structure over the middle burgher house at 6 Mostowa St. from the middle of the 16th century, all the structural elements are made of a whole tree, but of a different cross-section. Thick building material includes tie beams with an average cross-section of about 25 × 30 cm, medium material for rafters and collar beams 19 × 22 cm, and thin material upper collar beams 16 × 21 cm (Czaplicka & Hrycalik 2015).

Similar results follow from the architectural studies of other medieval roof structures of Toruń's burgher houses, for example at 10 Żeglarska St., 15 Kopernika St., 12 Świetego Ducha St., and at 20 Rynek Staromiejski St., which, however, are now without the original tie beams (Mielke 2019).

6 TIMBER PROCESSING METHOD

In the previous research on the wooden structures of Toruń from the early-14th to the mid-16th century, no differences in the processing of wood building material were found. As stated above, a whole tree, a half-tree, a cross-tree, or a sixth of a tree were used in their construction. An analysis of the surfaces of structural elements showed that, depending on the cross-section used, they were processed using different tools.

Many elements of the roof structures show traces of transverse cuts located approximately 40–60 cm apart (Figure 10). These cuts attest to the pre-treatment of the building material with an axe in a carpentry yard, which is illustrated in many studies on wooden architecture or construction technology (Figure 11). To this end, the log was first placed on low trestles and secured with carpentry clamps. Then the carpenter, standing on the log, made the aforementioned cross cuts, and next removed the bark and fragments of wane by working along the log.

Figure 11. A carpentry yard with a carpenter standing on a log and making transverse cuts with an axe, 1531, cf. Binding et al. 1989.

Figure 12. Toruń, parish church of St John, roof structure over the north aisle, long and slightly tilted cuts on the rafters attesting to the smoothing of the building material with a broad axe.

Long, delicate cuts with a slightly rounded shape on the elements of the structure prove that, after the initial treatment with an axe, the surface of the building material was smoothed with a carpenter's axe (Figure 12) For this process, the carpenter used a carpenter's broad

Figure 13. A carpenter smoothing pre-treated building material with a broad axe, 1425, cf. Schadwinkel & Heine 1986.

Figure 14. Toruń, parish church of St John, the north roof structure over the aisle, a triangle remaining after splitting the material at the point where the saw meets on both sides.

axe with a long and slightly rounded blade sharpened on one side, which made it possible for him to obtain a fairly smooth surface (Figure 13) The small angle of inclination discovered on many structural elements of the axe cuts proves that during its processing, the material was placed on trestles, reaching a height up to less than a human hip.

While the whole tree was treated only with an axe and a broad axe, a hand saw, a frame saw, or a log saw were used to obtain a half-tree, a quarter-tree, or a sixth of a tree. This is evidenced by both oblique cuts unevenly running across the material and the triangles remaining after splitting the material at the point where the saw meets on both sides (Figures 14, 15).

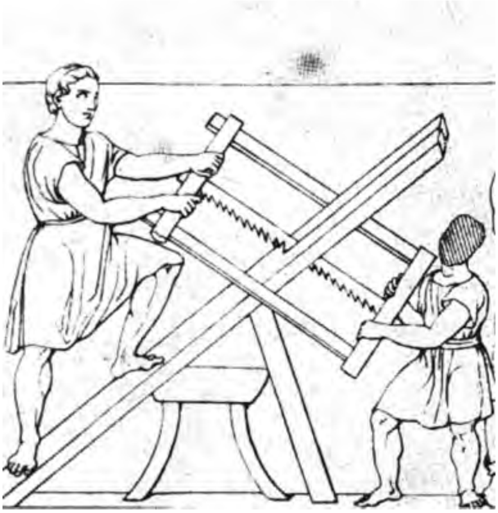

Figure 15. Dividing the building material into half-trees with a frame saw, Roman times, cf. Schadwinkel & Heine 1986.

Half-trees, quarter-trees, and sixths of trees are always made from a whole tree, so each such wooden element shows traces of processing with an axe, a broad axe, and a saw. In the research so far, no traces have been found that would make it possible to draw the conclusion that the whole tree was divided into smaller elements with a mechanical saw.

7 CONCLUSIONS AND OUTLOOK

This article is the first attempt at characterising wood as a building material in medieval wooden structures in Toruń.

Research has shown that the oldest roof constructions come from the beginning of the 14th century, while most of them were built in the 15th and early 16th centuries. The wood used for their construction comes partly from nearby forests, and partly from regions up to 350 km distant from Toruń. With such a large distance, the building material was transported by river, as evidenced by numerous traces preserved to this day on many elements of the constructions. These traces also prove that construction timber was transported in the form of logs joined together in rafts. These results shed new light on the medieval timber trade in northern Poland and raise the question of the reasons for the use of wood from such long distances in terms of economy and construction organization.

According to the dendrochronological analysis, pine wood was mainly used. Much less often it was oak wood, which was identified in the construction of one church with a significant span of the nave. In the case of secular architecture, oak wood could be found in the entablature above the cellars. This suggests that oak wood was a very valuable building material, the use of which was probably limited for economic reasons only to the most important construction tasks.

The construction timber used in Toruń can be classified in a simplified way into thick, medium, and thin. Architectural research shows that the whole tree was largely used as a building material for the main structural elements such as tie beams and the king strut, and semi-trees, cross-trees and, less frequently, sixths of trees were used for secondary elements, such as collars and passing braces. The whole tree was basically pre-trimmed with a broad axe and then smoothed with an axe, often leaving a wane. Only in a few cases has the use of an adze been found. Half-tree, cross-tree, and sixth of a tree were obtained by dividing the whole tree mainly with a handsaw, track saw, or frame saw. A preliminary review of professional Polish and German literature leads to the conclusion that the selection of the thickness of the building material and the method of its processing seem to be rather common.

The above-presented results regarding the medieval wooden building material of Toruń are only preliminary in nature. In the coming years, however, the research in Toruń will be continued, and the results will be compared with the research results from other regions, both in Poland and from foreign Hanseatic cities, to which union Toruń belonged in the Middle Ages. This will make it possible for both regional differences and similarities to be identified in the use of wood as a building material. Thus, they constitute a contribution to construction techniques and construction organization in Central and Eastern Europe in the Middle Ages.

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The glaziers' invoices from the Plantin-Moretus archives, 1600–1800

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ABSTRACT: Clear window glass is amongst the most neglected and underestimated historical building materials. Nevertheless, several studies have already shed light on the complex history of window-glass production. They have shown how its evolution led to different glass types, with different characteristics and significance, and that glazing was not just installed indiscriminately.

Although much insight was gained by studying glaziers' invoices, these have never been examined systematically over a large period. The glaziers' invoices in the archives of the Antwerp publishers' family of Plantin-Moretus give the opportunity to do both. Decoding these invoices from the 16–18th centuries not only holds the promise of more detailed insights into the glass types that existed in the past, albeit in a limited cultural, temporal and regional context; by revealing the differential uses of glass, they allow us to infer the potential cultural and social significances of window glass in urban dwellings.

1 INTRODUCTION

Of all historical building materials, clear window glass is among the most neglected and underestimated. During restoration or renovation projects, window glass in historical houses is all too often replaced by new glass. This is due partly to the fragility, inherent to the material, and to modern insulation standards, another major instigator of glass renewal; but primarily because of the general ignorance surrounding the complex history of window-glass production, despite being the subject of several studies (Belhoste & Leproux 1997; Blondel 1993; Lagabrielle & Philippe 2009; Louw 1991; Stokroos 1994; Tutton & Hirst 2007). Each of these has stressed how the evolution of window glass related to the evolution of architecture, not only to new developments in glass production, but also to consumers' changing wishes. They have clearly shown how this led to glass types with different characteristics and significance. Glazing was not installed indiscriminately, as this quote from a handbook by Jacques-François Blondel (1752–56) illustrates:

> "Il y a plusieurs sortes de verres: le blanc, le demi-blanc, & le verd: ce dernier ne s'employe que dans les lieux les plus ignorés d'un bâtiment: le demi blanc pour les maisons Bourgeoises, & le blanc pour les Hôtels, ou les maisons Royales, où l'on ne veut pas admettre les glaces, qui cependant aujourd'hui sont fort en usage, parce qu'elles annoncent plus de grandeur & de magnificence".

("There are many types of glass: white, semi-white and green: the last of these is only used in the least visited places in a building; semi-white is used in bourgeois houses; and white in hotels and royal houses or where *glaces* [polished cast plate glass] were not wanted, although these types are increasingly widespread since they denote grandeur and magnificence.")

Contemporary handbooks like this one are essential for the study of window glass, coeval witnesses of the existing glass types at the time, and sometimes including a description comparing and evaluating the various products. To what degree guidelines were implemented can then be traced in other source documents that directly show what glass was ordered by whom and used in what building. These archival documents include building specifications, correspondence between architects and their clients, and procedural documents about window glass. Nevertheless, glaziers' invoices provide a very valuable and neglected source. Their significance has already been acknowledged (Janse 1965; Van Doorne 1993), but their specific information has not yet been systematically utilized and still needs to be investigated more thoroughly.

The focus of this article is on the collection of accounts of the Antwerp publishers' family of Plantin-Moretus. These contain glaziers' invoices from the late 16th to late 18th centuries, giving a detailed description of the tasks the glaziers carried out, including what kind of window glass was installed, in what building (city residence, country houses, rental houses, and so on), and even at which location (printing room, library, kitchen, stables, etc.). In total, the invoices contain more than 10 different denominations for the types of clear glass, some of which appear unknown to current understanding. We cannot assume that all invoices have survived, and not every glazier reported

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his activities in the same detail, which sometimes complicates the analysis. Nevertheless, decoding these invoices not only holds the promise of more detailed insights into the glass types that existed in the past, but by testifying of the differential uses of glass, they allow us to infer the potential cultural and social significance of window glass in urban dwellings.

2 THE GLAZIERS' INVOICES OF THE PLANTIN-MORETUS FIRM

The former residence and workshop of Plantin-Moretus in Antwerp, now a UNESCO World Heritage site, has a complex building history. After moving to the house at the Heilige Geeststraat/Vrijdagmarkt in 1576, Christoffel Plantin (1520–1589) made several changes, including erecting a print shop and several side buildings. His successors, the Moretus family, enlarged the building and the print shop in 1620 and continued their building activities until the 1760s. Thanks to the extraordinary archives of the Plantin-Moretus family, many details are also known about the history of the window-glazing programme.

Covering more than two centuries, the glaziers' invoices abound. The first date from 1579, the year Plantin bought the house he soon called "den Gulden Passer" ("the Golden Compass"). The last invoice is from 1783 and was addressed to Mrs. Moretus, probably Maria Theresia Borrekens (1728–1797), the widow of Franciscus Joannes Moretus (1717–1768). The invoices are spread over several folders, most of them bundling together contracts and invoices linked to construction works from 1579 well into the 18th century.

What makes these invoices so interesting is that they give a detailed overview of the works the glaziers carried out, beginning with the client's name as well as the location of the works. The location concerned not only the building – indeed, the family owned more than one residence, including several rental houses – but very often the rooms within those buildings as well. As such, the invoices give a picture of what day, or in what period, the glazier was active in a certain property. Moreover, comparison is possible of the work done in different buildings – even within a particular building – and a trajectory can be reconstructed for an individual glazier's work programme.

2.1 *The glaziers' jobs*

Apart from the fact that the glaziers' invoices allow us to follow the constructional developments, illustrated by the installation of the new windows, they also give insight into other maintenance processes, such as re-leading of the glazing and window repair or cleaning.

When new glass had to be inserted, the glaziers spoke of "pieces" (*stucken*). But often they were more precise, using terms like *ruyt* (pane, but also quarry), *viercant* (square) and *rondeel* (roundel), which refer respectively to a pattern of quarries (lozenges) or squares and the insertion of a single roundel (not stained, in these invoices). Indeed, looking at how windows were generally glazed in the 16th century, both the lozenge-pattern and the square-leaded pattern were common. However, from the second half of the 16th century, the so-called Flemish Renaissance pattern was in vogue. This kind of panel combines rectangular glass pieces with hexagonal pieces, the latter forming a cross, dividing four rectangular pieces. Although we must remember that the Plantin-Moretus invoices are not complete, it is remarkable that almost every time the glazier put square pieces in a panel, he also put crosses (*cruijsen*) in it. This suggests that crosses indicated the hexagonal pieces in a Flemish Renaissance panel, which Félibien defined as "*borne en pièces quarrées*" ("edged with squared pieces") (Félibien 1676).

Concerning the shape and type of windows used, the glaziers left few clues, although, on one occasion, the windows in the Gulden Passer were described as cross-windows, each consisting of six panels (*ider cruijs raem sijn 6 gelasen*). Furthermore, the glaziers often spoke of "stone panels" (*steenglasen* or *steenpanden*) and "window panels" (*raamglasen* or *raampanden*). The latter can probably be interpreted as the panels intended for the wooden frames, whereas the former were the panels to be installed in the stonework. Indeed, in cross-windows, the upper lights had their glazing fixed directly with mortar in the stonework, while the lower lights were nailed into the wooden framework (Figure 1).

Figure 1. Cross-window in the Gulden Passer, situation after 20th-century reconstruction.

3 A VARIETY OF GLASS TYPES

The next aspect that the invoices illuminate is the use of different types of glass. The glaziers often noted what type of glass they had delivered or used while making, repairing, or otherwise treating the windows. In total, 14 different categories of glass could be identified: French glass, common glass (called *slecht glas* or *gemeijne ruijt*), Lorraine glass, new glass, old glass, Bohemian glass, Burgundy glass, glass of the glazier (*mijn glas* or *ons glas*), glass supplied by the client (*ulieden glas*), Italian glass, Louvain glass, Sarmolin glass and white glass. Most of these names seem only to suggest the origin of the glass; however, some regions were renowned for producing a certain type of window glass, often distinguished by particular properties. When production was transposed to other regions or even abroad, the name of the glass referred to the qualities of the glass, not necessarily to the place of production. Further research is needed to better understand the differences between all these glass types, but based on previous archival and literature research, we can draw conclusions regarding the types most commonly mentioned in the Plantin-Moretus archives.

3.1 *The evolution of the window-glass production process*

The large variation in glass types is not surprising, as the invoices cover the period from the late 16th to the late 18th centuries. During this period, window-glass production in Europe underwent several changes, including the emergence of the Southern Netherlands as an important glass production centre, the use of new technologies, leading to new types of window glass, and further popularization of this building material.

Previously, and since the 14th century, there had been two main window-glass production regions in northern Europe, each using their own technique: in Normandy the crown glass technique was practised, while the Lorraine region – and, by extension, Burgundy and the region more eastward near the Rhine – produced cylinder glass. That is why “Normandy glass” or “French glass” is synonymous with crown glass, while “Lorraine glass” – but also “Burgundy glass” and “Rhenish glass” – meant cylinder glass (Caen 2009). The existence of these two glass types is found in various archival documents regarding the use of window glass, even in Flanders and Brabant. Firstly, there was the ordinance, which glaziers belonging to the Antwerp Guild of St Luke had to follow from at least 1470 (Caen 2009). This Antwerp ordinance of 1470 – repeated in later years – stipulated the use of French glass unless the client had given permission to deploy Rhenish glass. The warning not to seek profit by invoicing French glass while using other glass suggests that this French glass was more expensive. A century later this was still the case, as illustrated by the invoice for Antwerp City Hall, rebuilt after the fire of 1576. It shows that two glass types were used: French and Burgundy. The French glass cost 1.5 stiver a piece, while a piece of Burgundy glass cost one stiver. (For comparison, at the end of the 16th century a 1.42 litre jar of beer cost about 3 stivers) At the end of the 17th century, the same distribution of prices can be seen in the invoices of several Antwerp families. This difference was certainly not exclusive to Antwerp: the 17th- and 18th-century invoices for Ghent City Hall feature French glass and Burgundy glass (Van Tyghem 1978). In Bruges, a 1674 document mentions the delivery of Burgundy glass for four stivers per foot and French glass for six stivers per foot (Caen 2009).

Around this time, in 1673, a new edition of *L’architecture françoise des bastimens particuliers* by Louis Savot was published in Paris. As in the first edition of 1624, Savot distinguished two types of window glass: the Lorraine glass which sold at five *sous* per foot, and the French glass, sold at six, though seven or eight *sous* per foot was also common for the best pieces. He commented that, of these two types, the French glass was the most beautiful and that the best – and most expensive – pieces were situated away from the central bullion or punty (“*quand il est choisi bien droit & eloigné du bossage du plat*”). Indeed, as several other authors explain, French glass was typically made using the crown glass technique, resulting in glass discs with a thickening in the middle (Blondel 1752–56; Caen 2009; d’Aviler 1700). Further away from this bullion – with the exception of the edge – the thickness of the glass was more even. And, as Savot wrote, the straighter and thus the more even the glass, the more beautiful it was. Savot also described ugly glass: “*plain de nœuds & graviers, estant jetté en sable*” (“full of ripples and grit, having been thrown in sand”). He was referring to the other main technique for producing window glass in those days: the cylinder technique. Unlike crown glass, the surfaces of cylinder glass had to be touched and manipulated to flatten them. This was done with a wooden block, which left streaky impressions. Furthermore, the base on which the glass was laid out to be flattened caused its own imperfections. The surfaces of cylinder glass were therefore less shiny, whereas exactly because crown glass was literally “untouched”, its surface was fire-polished during the process when the bowl was transformed into a disc, and therefore brilliant (Peligot 1877; Salvetat 1920).

By the time Savot wrote his book, the Lorraine production had experienced serious difficulties due to overproduction and the competition from Normandy glass and the Italian glass industry (Rose-Villequey 1971). Fiscal pressure, religious wars and the destruction of their kilns in 1636 had also contributed to the emigration of Lorraine glass blowers, from 1567 to the early 17th century (Caen 2009; Rose-Villequey 1971). In the south of the Low Countries, primarily around Liège, Hainaut and Namur, the glassblowers had found a new home and imported their cylinder glass production, so use of the term “Lorraine glass” became less appropriate unless it really came from that region.

New factories in the Southern Netherlands produced window glass *à la façon de Lorraine*, although they were open to other methods and innovative techniques. One of these novelties came from Bohemia and consisted of the creation of a very clear glass, which could be blown in rather thick plates. It was developed at the end of the 17th century and was introduced to the Southern Netherlands in 1726, where it was first produced in Charleroi (Crismer 1978; Douglas & Franck 1972; Lefrancq 2015,). Due to its quality, but also because of its higher production costs, this Bohemian glass – or glass *façon de Bohême* – was applied exclusively in the windows of rich men's dwellings, in carriages and as a protection for etchings and other artwork. Elsewhere, cheaper glass types, like the French and Lorraine glass, were used (Blondel 1752–56).

However, this Bohemian glass was not the only "luxury glass". France had developed and perfected the production of polished cast plate glass in the second half of the 17th century. Originally destined to serve as mirror glass, and therefore perfectly flawless and even, these *glaces* were the most exclusive of all glass types, rivalling only those of the Italians, long reputed for their glass and mirrors. Nevertheless, at least in the Netherlands, the competitiveness of Italian glass was not affected by the arrival of the French *glaces*. Several 19th-century architectural handbooks still recommended Italian glass as one of the most beautiful glass types (Brade 1828; Pasteur 1850; Simis 1829). To what extent this Italian glass indeed always originated from the Mediterranean peninsula is not known, as Italian glasshouses had been established in Antwerp, for instance, since the 16th century.

3.2 *The Gulden Passer*

As mentioned above, the Plantin-Moretus family possessed several buildings: from the Gulden Passer, a conspicuous urban dwelling, to countryside residences and several rental houses, hence covering a large tranche of the social spectrum. In all these buildings, glaziers were employed. Nevertheless, the Gulden Passer was the epicentre where the glaziers made, delivered, repaired, adjusted, fixed and cleaned the windows. The number of recorded glass types in the Gulden Passer is very revealing, though not all of them are equally represented in the invoices, and only the most important will be discussed (Table 1).

Table 1. The presence of the different types of glass (number of mentions in the invoices) in the main categories of buildings owned by the Plantin-Moretus family.

	Type of building			
Type of glass	Country House	Gulden Passer	Rental house	Total
Bohemia glass	1	3	0	4
Common glass	0	136	27	163
French glass	6	390	79	475
Italian glass	0	6	0	6
Lorraine glass	0	18	0	18
other glass	1	26	8	35
Sarmolin glass	5	0	0	5
Unidentified glass	149	1191	678	2018
Total	162	1770	792	2724

3.2.1 *French and common glass*

The glass type most mentioned is "French glass", followed by "common glass". These could be regarded as opposites, as the glaziers themselves suggest by noting simultaneously the use of "French glass and common glass", or "French glass and other glass".

Looking at the invoices, the first difference is in price: while a piece of French glass cost 1.5 to 2 stivers, a piece of ordinary glass cost one stiver. This corresponds to the abovementioned price settings of French glass and Burgundy glass in diverse archival documents. Yet, in the Plantin-Moretus invoices, Burgundy glass and Lorraine glass were noted only a few times: Burgundy glass was mentioned once, in 1579, and Lorraine glass only in the years 1620–1625. As this is the period when the Lorraine glassblowers emigrated to the Southern Netherlands, it is plausible that this "local" production had started to deliver "common glass", the cheaper, more commonly used glass, rather than the more expensive French glass. However, although these new factories made glass *à la façon de Lorraine*, some of them also produced *à la façon de France* (Lefrancq 2015), meaning that the "French glass" distributed in the Low Countries may never actually have been in Normandy. The old name may have been kept to distinguish the two production methods, and the fact that it concerned crown glass would still apply.

The Antwerp ordinance of 1470 already hinted at the use of two different types of glass at the same time; having said that, if Rhenish glass was used, this was only allowed on the left, right and upper sides of a window. This implies that the central part of the window, through which one looked directly, had to be made of the better French glass.

As Rhenish or Lorraine glass was greener, it was possibly avoided in the most prominent part of the window (Caen 2009; Van Doorne 1993).

Therefore, the placing of various types of glazing within a building was not incidental, as was confirmed by many authors from the 17th century onwards (Blondel 1752–56; Brade 1828; Bullet 1691; Savot 1673). The common thread running through their recommendations was that the best glass had to be put in the most visible, important and representative rooms.

Judging by the Plantin-Moretus case, it would appear that these instructions were put into practice, and these 17th-century guidelines were now part of a written record of reality and tradition. Indeed, investigating the glaziers' invoices of the Plantin-Moretus family reveals certain tendencies, such as French glass being by far the most preferred glass type. It was used at almost every location, from the attics, the stairs and the warehouse, in the printing workshop, the kitchens and the bedroom, to the library, the offices and the dining room. Ordinary glass was then the second choice: it was mentioned only half as often as the french glass,

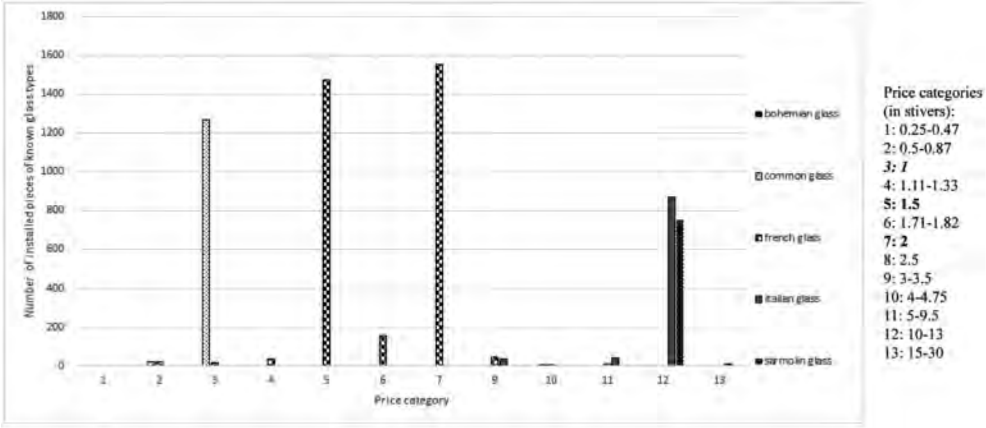

Figure 2. Price categories of the main known glass types. The prices concern those for one (new) piece of glass.

and at far fewer locations. Nonetheless, common glass was installed in lesser and better places equally, such as stairs, attics, library and dining room.

However, comparing the number of times the different glass types were used gives a distorted image: the glaziers did not always specify the glass they had used, only identifying it as special when it seemed relevant. Thus, a slightly different picture emerges when focusing on the price of the glass. As mentioned above, the difference between French glass and ordinary glass is revealed by the price, with French glass costing up to twice as much as ordinary glass: 1.5 to 2 stivers for a piece of French glass versus one stiver for a piece of ordinary glass. The other types of glass generally seem to have had their own, different prices. Even when the glass type was not mentioned by the glazier, its existence can be deduced from its listed price, not least because the prices seem to have been stable throughout the period in question (Figure 2).

Subsequently, I investigated how often and in what locations the new one-stiver pieces were inserted, compared to those of 1.5 and 2 stivers. This revealed that the one-stiver pieces were slightly in the majority, appearing 312 times, versus 298 times for both the 1.5 and 2 stiver pieces.

Looking at how many pieces were actually installed; we see 3638 one-stiver pieces versus 2877 pieces of 1.5 or 2 stivers. From this perspective, the theory of French glass being the first choice makes less sense. On the other hand, certain locations are clearly linked to a specific price category. For instance, in the best room (*beste kamer*) only two-stiver pieces were used, while in the stables and the cellars only one-stiver pieces were installed. In most of the locations, however, there was no such strict division – not even in locations like the printing workshop, the correctors' room, and the sorting room, where one would expect the best lighting conditions.

All this seems to confirm the underlying considerations when choosing a specific glass type. On the one hand, the locations where bright daylight was required but which were above all of a certain standing – such as the library, the best room, the offices and the dining room – contained mostly to exclusively the more expensive glass. In the stables, the cellars and the attics, it seemed to matter less if the glass was of a lesser quality. This could also explain why the one-stiver pieces were in the majority at locations full of activity that probably had to be ventilated more often by opening and closing the windows, and where the hustle and bustle in these rooms entailed a higher risk of breakage.

3.2.2 *Italian and Bohemian glass*

Other archives – in particular glaziers' invoices from other wealthy families – show an increase in glass types as of the 18th century, together with a calculated use of the most expensive glass types in, for instance, vestibules, lanterns and façades (Langouche forthcoming). This is also true for the Plantin-Moretus invoices where portals and lanterns occupy a special position – although one-stiver pieces were occasionally present in both locations, most pieces were more expensive. Furthermore, glass inserted here could cost three to twenty-one stivers a piece. Although, for instance, a large piece of French glass could cost seven stivers, these more expensive pieces were mainly Italian and Bohemian glass. Both Italian and Bohemian glass appeared in the Plantin-Moretus invoices in the 18th century and were highly esteemed by contemporaries as very clear and/or solid (Belhoste & Leproux 1997; Crismer 1978; Godfrey 1975; Lefrancq 2015). Blondel was very precise: the beautiful white Bohemian glass panes were a lot larger and stronger than the French or Lorraine glass: because of its whiteness, it was installed in places that needed a lot of light; its thickness made it more resistant to shocks; and its size allowed relatively large pieces to be cut from it. (Blondel 1752–56).

This third asset may not have been the first reason for using Bohemian glass in lanterns, but its solidity certainly was. In 1762, Jan Baptist Geerrits asked nine stivers for one Bohemian pane, destined for the lantern of the coach (*kots lantairel*). Given that glass

Figure 3. The façade of the Gulden Passer on the Vrijdagmarkt, as designed by Engelbert Baets and built in 1761–63.

in carriages had to be extra shock-proof, and therefore extra thick, a more expensive glass type was necessary. The same applied to the glass in portal doors, which tended to be slammed shut, if only by the wind. Consequently, the glass had to be solid enough and of good quality. This explains why the Bohemian glass was only found in the portal, including the semi-circular upper part. To illustrate: in 1766, Joannes van Geel fixed two large white Bohemian panes, one in the portal and the other in the arcade above the portal (*den bogh boven de poort*), for which he asked respectively 11 and 21 stivers. In this case, the size and clarity definitely played a part in the choice of Bohemian glass. Prestige was also a consideration: Franciscus Joannes Moretus may have wanted to make a good impression by using this fine glass where his visitors entered the house (Figure 3).

That same consideration may have played a role in the entire construction of the new building at the Vrijdagmarkt. Starting in 1761, architect Engelbert Baets erected a new wing, connected to the existing part of the Gulden Passer and looking onto the Vrijdagmarkt, which had been a popular marketplace for centuries. Formerly, a series of smaller houses had stood there, leaving only a corridor leading to the Moretus building. After their demolition, the Gulden Passer was a dominant presence. Instead of the renaissance style in which the old building had been constructed, the new façade was conceived in a sober but elegant baroque style. Besides a prominent entrance gateway and pilasters creating a certain stately ambience, the many windows also accentuated the grandeur of the new façade. Unlike in the rest of the building, no old-fashioned cross-windows were installed, but modern French windows, with the very best glass on the market. In 1762, the glazier Nicolas Wersier delivered 857 Italian pieces that cost 12 stivers each. Their total sum of 514 guilders and four stivers was the largest single expense for the delivery of glass ever at Plantin-Moretus.

3.3 *Other residences*

Through purchase, construction and inheritance, the real estate of the Plantin-Moretus family changed over the years. The Gulden Passer incorporated adjacent houses, some of which were rented out. The family possessed several other rental houses in Antwerp, in addition to which they purchased or inherited villas or castles in the countryside. As owners of all these houses, they had to take care of the maintenance and regularly employed glaziers to work there, as shown in the invoices.

In the rental houses a similar use of French glass and common glass can be discerned as in the Gulden Passer, the French glass being the most mentioned, but the one-stiver pieces being installed most often. There is no trace of luxury glass in the rental houses, although in 1779 J.N. De Wersier mentioned delivery of 754 Sarmolin panes (*sarmolijnce ruijten*), together with two panes of Bohemian glass. The destination is not clear, but as it had been ordered by the dowager Moretus, one hypothesis is that De Wersier worked in the Bisschoppenhof in Ekeren-Donk. In 1775 Maria Theresia Borrekens, widowed since 1768, had bought this castle, said to have been her favourite country house. Possibly she had it renovated a few years after its purchase and used the Bohemian glass she had ordered. At a cost of 105 stivers a piece, it was by far the most expensive window glass in all of the Plantin-Moretus invoices. Sarmolin glass, at 10.75 stivers per piece, was also from an ordinary glass type.

4 CONCLUSION

Further research will deepen our insights because these glaziers' invoices are just a collection of accounting information, not always complete or clear, and say nothing about the appreciation for the diverse glass types. The invoices have to be placed in a broader economic and cultural context, and compared with more, similar material. Nevertheless, the Plantin-Moretus archives constitute a highly interesting case study for a rich Antwerp family in the early modern period. Its glaziers' invoices represent a rich source of information about the availability and application of different types of window glass from the late 16th to late 18th centuries, a period which saw several evolutionary phases in the history of glass production, often resulting in new glass types. Especially the late 17th century saw the introduction of new, high-quality glass types such as Bohemian glass and the French *glaces*. Being successful publishers, the Plantin-Moretus family could afford the most expensive glass available.

Unfortunately, not all sorts of glass are equally represented in the invoices, which means they cannot all be studied in the same detail. Others will be the topic of further research. However, luxury glass types were found at very distinct locations: in the lanterns, the portals and in the new façade on the Vrijdagmarkt, which called for strong and clear glass. As glaziers' invoices from other archives seem to confirm, the prestige and visibility of these locations were decisive, and this targeted luxury went further, as we have also seen in the kinds of applications of French and common glass: in locations such as the cellars, the stables and the foundry ordinary glass predominated, while in the rooms that had a certain prestige, best rooms, the library, the dining room and the offices, French crown glass was preferred.

In locations where both glass types were inserted, possibly the procedure described by the Antwerp guild ordinance of 1470 was followed: French glass in the central part of the window, surrounded by ordinary glass. This must also have been the case in locations such as the printing workshop, the correctors' room and the sorting room where activities required the best light conditions. Nevertheless, no luxury glass was installed here, only the combinations of French and common glass. After all, the primary merits of having luxury window glass were its specific material characteristics, such as its size, flawlessness or strength, leading to its well-defined applications. But maybe more important was the social significance of these types of glass, which were meant to be seen and admired.

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History of Construction Cultures – Mascarenhas-Mateus & Paula Pires (eds)

The House of Mercy of Lourinhã: Contributions to the history of construction in the early 17th century

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ABSTRACT: Between 1618 and 1623, the House of Mercy of Lourinhã underwent a construction campaign that gave rise to the current building. The work was prompted not only by the ruin of the building, but also by the need to adapt it to new use, as the Confraternity of Mercy had their own dynamics. The exact work is not specified but, based on data from historical documentation, it seems to have involved enlargement of the old building. The intervention had an architectural nature in which local professionals and materials were used, but the project was not thus restricted. The central source for research was the income and expense books, an important source on the history of the construction. These documents are virtually unexplored, as they were integrated into a private archive. They allow us to characterise and analyse this campaign of works and its diverse components from the perspective of the construction history.

1 INITIAL CONSIDERATIONS

Between 1618 and 1623, the House of Mercy [*Casa da Misericórdia*] of Lourinhã underwent a construction campaign that gave rise to the current building, about which little is known. Although it is a construction site with limited size and scope, surviving documentation provides knowledge of its contours (unlike other sites for which there is no documentation). It therefore has value in a micro-historic context.

The project was prompted by the ruin of the building, but certainly also by a need to adapt it to new use. This is because the Confraternity of Mercy (or *Misericórdia*) had their own peculiar dynamics, as evidenced in their statutes. The exact work carried out is unspecified; however, based on data from the historical documentation analysed, it seems to have involved enlargement and adaptation of the old building. The intervention was architectural in nature, albeit not thus restricted.

The income and expense book provides the primary source for our investigation. These are important sources for the history of construction, as they contain information not found in other documents. However, they should be combined with other source typologies, because they are not very descriptive, given their characteristics and function.

As a topic, 17th-century architecture deserves greater attention from historiography. The specific case we discuss in this paper benefits from the existing building, which essentially corresponds to the construction campaign to which the documentation refers. The documentation is virtually unexplored, as it was integrated into a private archive. The sources allow for the characterisation and analysis of this campaign and its diverse components from the perspective of the construction history.

2 THE CONFRATERNITIES OF MERCY

The first Confraternity of Mercy was founded in Lisbon in 1498. Given its purpose of providing social assistance, it was promoted by laymen with support from the king and the royal house. In the ensuing decades, institutions within the country and abroad succeeded each other; the *Misericórdias* became the most prominent assistance institution in Portugal during the Early Modern Age (Sá 2001; Sousa 1998). These confraternities were established in both large cities and small villages, creating a network of assistance for the needy. This network also provided a means to mobilise local elites, contributing to their prestige and social mobility. Mercies are thus an important object of study, not only in terms of social and political history, but also as part of the history of art and architecture. To achieve the aims of their assistance programmes, these confraternities needed a space – the House of Mercy – for gathering the brothers together, celebrating mass, treating the sick, welcoming pilgrims, and storing their goods. The historical importance of *Misericórdias* also stems from the fact that these institutions have been in continuous activity from their conception to the present day, despite some adaptations and transformations in their assistance practices (Paiva 2002–2011) (Figure 1).

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Figure 1. House of Mercy of Lourinhã, main façade (photo: Joana Balsa de Pinho).

2.1 *The confraternity of mercy of Lourinhã and assistance in the village*

The *Misericórdia* of Lourinhã was founded in 1586 through a charter from King Philip I (ANTT, Chancelaria de D. Filipe I: privilégios, *Livro* 1, f. 223v.). The same charter associates the *Misericórdia* with welfare institutions in the village, the Espírito Santo hospital and the lazarette, whose origins date back to the medieval period. Similar mergers had occurred in other regions throughout the country.

In the context of this association, the *Misericórdia* was installed at the House of Espírito Santo [Holy Spirit]. The Confraternity of Espírito Santo, the owner of the building, had appended the care homes of Corpo de Deus and Santa Margarida in 1503 (AML, *Book of Tombo da Albergarida and brotherhood of Santa Margarida*, f. 9). At the time of this association, the construction of a new hospital had been underway for at least three years. The hospital project had benefited from several royal donations, but by 1516, the work was still not completed (AML, *Tombo da albergaria and confraternity of Santo Espírito*, f. 1v.). At the end of the 16th century, this building was occupied by the *Misericórdia*. It would be remodelled in the first decades of the 17th century, leaving intact only a late Gothic portal.

2.2 *Administration, management, and daily life in the confraternity*

The Confraternities of Mercy were managed by a group of 12 brothers (consisting of a provider, a treasurer and officers). This group was elected annually by all members on 2 July, the day of the Visitation of Our Lady to Saint Isabel, the festivity and main devotion of the confraternity. For this reason, the so-called 'confraternal year' also started on this day. Officers met weekly in the House of Mercy and were responsible for making decisions and managing the activities and assets of the confraternity.

The administrative life of the *Misericórdias* was organised around records written by the brothers on elections, officers' meetings (decisions), and the balance of income and expenses. These records were written in either separate books or a single book, depending on the complexity of the confraternity and its social importance, economic power and assistance activities.

In the case of Lourinhã, there are two types of books: one records the decisions, elections and entry or dismissal of brothers, while the other registers income and expenses. As we shall see, these documentary sources are complementary. The former is older than the latter, as it begins with the *Misericórdia*'s foundation in 1586. It is thus more complete, although its records were less frequent. The latter is more consistent, with regular annual records. The oldest book covers the period from 1618 to 1623, while some other folios refer to the years 1594–95 and 1595–96.

3 THE 17TH-CENTURY CONSTRUCTION CAMPAIGN

3.1 *Motivation and decision-making*

The main reason behind the work done on the House of Espírito Santo at the beginning of the 17th century was the ruin of the building, as reported in the record of the officers' meeting on 12 January 1614 (AML, *Livro dos acordos da mesa* (1586–1643), ff. 133v.-134). However, there may have been another cause for this intervention. When the Confraternity of Mercy of Lourinhã was founded at the end of the 16th century, it was installed in a pre-existing building; this practice was common to other *Misericórdias* (Pinho 2012, 149–86). In addition to being old, the pre-existing building had not been built to serve as the *Misericórdia*'s headquarters. The intervention at the end of the first decades of the 17th century apparently sought to remodel and expand the building such that it would serve the needs of the confraternity. The buildings of the Houses of Mercy had architectural and spatial features related to the actions they performed in daily life and within the organisational structure of the confraternity (Pinho 2012, 186–224).

There was an awareness of the building's overall state of ruin along with the risk of the altarpiece collapsing, which led to the consequent need for intervention. It was decided that the brothers should gather together and survey construction professionals for their opinion on the proposed intervention: "because this house of mercy was ruined, in great danger of falling and its altarpiece could collapse […] they agreed to call all the brotherhood, so that together […] they could choose what seemed best, with the opinions of the mason and the carpenter, called for and gathered together to fulfil that aim" (AML, *Livro dos acordos da mesa* (1586–1643), ff. 133v.-134) (Figure 2).

Figure 2. House of Mercy of Lourinhã, late Gothic portal (photo: Joana Balsa de Pinho).

But the work carried out between 1618 and 1623 was not merely a consolidation of the building; it was rather more extensive. Although the accounting records are not detailed and do not clearly define the work, there were payments for pilasters, cornices and portals that seem to suggest the configuration of a new building.

3.2 *Chronology and evolution of the works*

The construction campaign arose from the decision to intervene in the building, given its state of degradation in 1614. This began by dismantling part of the altarpiece and propping up the roof (AML, *Livro dos acordos da mesa* (1586–1643), ff. 133v.-134). The start date of the works is unknown, but the first payments were registered in 1618. Indeed, only payments were registered. For the entire period, there are no other records of the brothers' meetings related to the construction campaign that might allow us to glean other details (Figure 3).

Payments continued until 1622–23. The expense book from the 1625–26 period contains no payments related to the project. As the year 1626 is inscribed in the main portal lintel, the campaign seemingly ended then.

Expense records follow the construction progress: during the early years of the project, payments were made for stone mining and the purchase of various materials. In later years, money was spent on building specific architectural elements such as cornerstones, entablatures and portals, and on several workers and specific tasks. The architectural campaign would have been over in 1622–23, as there was the purchase of a large quantity of planking (f. 106v.) that was clearly meant for ceilings and wooden floors, suggesting the closing phase of the works. The final payments refer to expenses such as dust (AML, *Livro de receita e despesa*, liv. 2, f. 117v. [henceforth designated only by the folio]) and stone removal from the street (f. 123), indicating that the works were likely completed.

Figure 3. House of Mercy of Lourinhã, church façade (photo: Joana Balsa de Pinho).

3.3 *Nature of the works*

While other works are mentioned, the construction campaign documented in the income and expense book under analysis is an eminently architectural intervention. The type of intervention is not specified; there are neither records for determining execution nor a contract establishing conditions. However, documentary references highlight the architectural nature of the work by detailing the tasks carried out by masons, the names of the masons, the construction of certain architectural elements, and the purchase of materials for their execution (providing further information and registering these purchases in separate notes).

Combining the analysis of the architectural remains of the House of Mercy of Lourinhã with the documentary references under study (ff. 24v., 48v.), it becomes evident that the final outcome of the intervention followed the House of Mercy model, which was developed and implemented by these confraternities throughout the 16th century (Pinho 2012, 186–224). The architectural ensemble included a church, a meeting room [*casa do despacho*], a sacristy, an infirmary and other facilities, and a yard. The building underwent new interventions in the 18th, 19th and 20th centuries, thus the comparison of documentary references with architectural remains is limited.

We know for certain that, with the construction of the new hospital to the west of the church in 1793,

Figure 4. House of Mercy of Lourinhã, pilasters (photo: Joana Balsa de Pinho).

the 17th-century structure was altered, considering the way in which the sacristy was integrated into this building. In regard to a stylistic analysis, the only remnants from the architecture campaign begun in 1618 are the church and the sacristy. The construction campaign likely also intervened in dependencies such (Figure 4) as the meeting room of the officials and the old hospital, although the documentation does not clarify this. The only explicit note concerns the sacristy, which might have been object of a carpentry campaign, receiving a new floor and roof in 1619–29 (ff. 63 and 63v.). Unfortunately, later interventions – some of them lacking architectural qualification – render a full confrontation between documentary references and architectural remains impossible.

3.4 *Materials and auxiliary means of construction*

There are abundant records of the purchase of materials. They include the amounts spent and, more rarely, the quantity of materials purchased, the suppliers and the place of purchase. There are differences in information from year to year, depending on the registrar who did the recording. Materials purchased between 1618 and 1623 include sand (ff. 27, 29v., 30v., 31v.), water (f. 26), lime (ff. 63, 63v., 103v.), stone (ff. 31, 31v., 32), bricks (f. 26, 27v., 63), sticks (f. 28), wood and planking (f. 117v.), tacks (ff. 28v., 63), tiles (f. 26), nails (ff. 26, 26v., 28v.), beams (f. 29v.) and slats (f. 63). Raw materials, such as a case of lead to make screws (f. 63v.), were also purchased.

The account book mentions other expenses related to the transportation of materials. Along with wood and stone (f. 102v.), lime (103v.) was carried using wagons and boats. For this reason, there were several payments to drivers and boatmen. One interesting record notes an expense "to repair the road for stone to arrive" (f. 30).

While the provenance of the stone is unknown, given references to certain professionals on the construction yard (who also mined stone at the quarry), it presumably came from one of the local quarries. Payments for several shipments of stone were made to Álvaro Anes (f. 27), Janeiro das Matas (ff. 27, 32), Francisco Vaz (f. 27v.), António Luís from Montouto (f. 28v.), António Fernandes and his cousin from Trunqueira, Manuel Rodrigues and his son-in-law (ff. 31., 31v.), and João Luís from Pragança (f. 32). Considering the mode of transport and the typology, the stone could also have been from the Lisbon region.

Regarding the wood used, the records show that the planking came from Caldas da Rainha (f. 26). Other shipments of wood disembarked at the Ribamar beach (f. 63), a town about 6 km from Lourinhã. It appears that the same type of material was provided by different suppliers. Even small materials such as tacks were bought from two different providers in 1618: Diogo Rodrigues and António Dias (f. 26).

Annual changes in registrars interfered with the way in which registrations were made, especially in terms of the type of information that was registered, the amount of detail, and the general structure of the account. With the change of registrar between 1618–19 and 1619–20, significant differences can be seen. Records became more detailed, revealing more interesting and relevant data. For example, a total of 1400 nails were purchased in Lisbon (f. 62v.) over this period. Likewise, the supplier of the tacks is 'Alemão' [*German*]; the tile supplier is 'Solteiro' [*Single*] (f. 63); and lime was purchased from Domingos Fernandes, Toxofal de Cima and André Fernandes (f. 63). In 1622–23, registration again follows a different format, and expenses for works appear in a separate list independent of the other expenses of the confraternity (ff. 106v.-118). The entries are also presented more systematically.

References to auxiliary means of construction are rarer in the account book of the Misericórdia of Lourinhã, with only allusions to the acquisition of ropes (f. 105) and baskets (f. 31). In parallel sources from other Misericordias, references to the acquisition of materials for trusses, props and scaffolds for similar cases can be found. If these references are usually rare for other buildings (Pinho 2017, 2019), in the case of Lourinhã the absence is likely due to the chronology of the works carried out and to aesthetic reasons (that is, to the effective absence of arches and vaults in this construction) (Figure 5).

3.5 *Architectural elements and technical work*

As noted above, the construction campaign under analysis appears to be fundamentally architectural. Given the purchase of materials (stone, sand and lime) and the reference to specific architectural elements (portals, cornerstones and entablature), there was likely a

Figure 5. House of Mercy of Lourinhã, church portal (photo: Joana Balsa de Pinho).

Figure 6. Church of the House of Mercy of Lourinhã (photo: Joana Balsa de Pinho).

general intervention in the building, although we do not know exactly what type of work it involved. This hypothesis is confirmed when we analyse the artistic-architectural features of the current building, since what remains today – namely the church and sacristy – essentially corresponds to the outcome of this campaign: a campaign to expand the late medieval building constructed at the beginning of the 16th century, referred in the documents as the 'new' construction.

In the list of expenses, some architectural elements are treated differently (namely portals, cornerstones and entablature) depending on either the purchase of stone for its execution or payment to the officers who executed it. The stone for the corners cost three *vinténs* per *vara* for a total of 2400 *reis*, or 40 *varas*, supplied by Bastion of Ceita (f. 104). Considering that the average height of the current pilasters is 7 metres, and that each *vara* corresponds to 1.10 metres, the acquired stone would have allowed for the construction of about six pilasters. Three still exist in the main facade of the building, with counterparts possibly in the back.

For the entablature, 9 *varas* of stone were purchased at 80 *reis* each for a total of 720 *reis* (f. 104), which would correspond to the finishing of the main façade of the House of Mercy. This includes the church and the adjoining building; the original finishing was later transformed. The entablature cannot have been applied to the finishing of the lateral façades, as the building was adjacent to other constructions. Two portals of 10 spans each cost 800 *reis* (f. 104), the stone for the discharge arch cost 200 *reis* (f. 104), and two *varas* of slabs cost 100 *reis* (f. 104).

The income and expense book portrays (albeit briefly) the entire cycle of stonemasonry from mining to transport, hewing and carving. Francisco Vaz and Domingos Rodrigues were paid to mine stone for two years in a row (f. 32, 63v.). Five stones for the portal and the cornerstone were mined by Bastião de Ceita for 2000 *reis* (f. 63v.) and 700 *reis* (f. 64), respectively. The first stones were transported by Marques (f. 64) at the cost of 1500 *reis*, while Bastião de Ceita was responsible for transporting the material for the cornerstone at the cost of 720 *reis*. Bastião de Ceita was sometimes paid for general stone carving (f. 102v.). In 1621–22, he received payment for work on one of the cornerstones, '*base, collar, entablature, slab*' [*uasa, colarjnho, simalha, lagem*], amounting to a total of 6000 *reis*. Diogo Dias, a stonemason, received the entablature and *collar* to build two portals and a half cornerstone (f. 104v.).

In terms of carpentry work, the only existing technical mention pertains to the intervention carried out in the sacristy. The sacristy was lined with trusses using fifty large nails and three hundred tacks (f. 63).

3.6 *Professionals, master builders and officers*

The professionals who worked on the project are the second point of attention in the income and expense documents. The available information mentions the diversity of crafts represented on the construction site. This includes masons (f. 28), carpenters and blacksmiths (f. 27), and sawyers (f. 26v.); their professional categories, such as officers, juniors (junior locksmith; f. 26v.), servants (f. 26v.) or officers' servants (ff. 102, 102v., 103v.); the amounts paid and days worked (Figure 6).

Many officers are designated by name only, without indication of their craft. The account book for the year 1618–19 mentions Bartolomeu Fernandes, Pero Fernandes, Pero Afonso, Diogo Rodrigues, António Martins, o Ribeiro, Brás Dias, Marçal da Costa (f. 28v.), João Ferreira, o Coutinho, Pero Rodrigues (f. 29), Domingos Rodrigues, Peixoto, o Ruivo, António Alves/Alvares, Domingos Dias and António Fernandes, (f. 31.), among others. Masons abound in this group, as confirmed by the references. For example, Lourenço Martins and Leonardo Monteiro were paid "for the work they did as masons" [*do serviço que fez de pedreiro*] (f. 28), while João Sá and Leonardo Martins are directly designated as masons (f. 103v.).

Allusions to the provenance of these officials are rare. In the unique case of António Martins, the registration notes that he came from 'Toxofal' (f. 32), a town about four kilometres from Lourinhã.

Within the group above, the name of Bastião de Ceita stands out because he received a higher salary (f. 28v.) and his work was described in a separate section: "item plus the Seita for hewing stones for three

Figure 7. Tribune room [*sala da tribuna*] House of Mercy of Lourinhã (photo: Joana Balsa de Pinho).

days, four hundred and twenty *reis*" (f. 30). Bastião de Ceita was paid regularly for mining and working on stone, until the end of the project in 1621–22 (f. 102). According to the data, Bastião de Ceita is probably the mason responsible for the works carried out at the House of Mercy of Lourinhã, instead of Bartolomeu Francês as indicated by some historiographies. Although Ceita performed a set of different tasks at the construction yard, such as those of the traditional master builder from the Medieval and Renaissance times. From 1620–21 onwards, payments were made to Bartolomeu Francês for performing "tasks on the construction" [*trabalhos na obra*] (f. 102) as well as to his servants (ff. 102, 102v.). The tasks he performed are never specified, and they appear late in the timeline of the construction campaign. Only because his servants were paid for "carving tasks" [*obras de picão*] (f. 102v.), as well as through other miscellaneous data, are we able to infer that Bartolomeu Frances was a stonemason (Figure 7).

4 FINAL CONSIDERATIONS

As documented in the income and expense book, the construction campaign that built the current House of Mercy of Lourinhã implicates a small and local construction site in operation for several years.

The analysis of this documentation contributes to the history of the construction of this particular building, considering the micro-historical approach. It also aims to contribute to the knowledge on the history of construction in Portugal during the early 17th century. The existence of few studies allowed for a general and comparative approach to the subject.

In light of their nature, the documentary sources under study enable more proper knowledge and understanding of the construction aspects of the House of Mercy of Lourinhã than the project conducted. Scholarship focusing on this typological documentary source will provide greater insights into the professionals involved (apart from the master builder or architect who typically signed the contract), payments, materials, suppliers, construction-yard functioning, proveniences, modes of transport, works and specific techniques related to certain elements of the construction.

Albeit on a micro scale, it is possible to perceive the organic nature of this type of construction campaign. In this specific case, the project ranged from preparatory to finishing work, from the construction of the street on which the stone was transported to the construction site to the cleaning of the dirt and stone streets following the project's completion. Although payments ended in 1622–23, and the account book of 1625–26 shows no payments related to the project, the main portal lintel carries the inscription '1626'. Therefore, it is possible to conclude that some unrecorded and minor work was done in the subsequent years.

Likewise, even this small construction yard hosted a multiplicity of professionals, most of whom were local, and there are signs of the existence of a hierarchy in which the officers and their servants worked. Some names remain and differ from the rest by a higher salary, diversity of performed tasks or the presence of servants at their service. Certainly, the most eminent was Bastião de Ceita, probably the mason responsible for the works carried out at the House of Mercy of Lourinhã, and not Bartolomeu Francês as some historiographies suggest. As seen from the beginning of the written records to the end, Ceita was assigned the most skilful tasks in terms of technique and aesthetic care. This confirms the architectural nature of the works documented between 1618 and 1623, which is reinforced by the detailed register of tasks carried out by the masons, their names, the construction of certain architectural elements, and the purchase of materials for these constructions registered in separate notes. Following *estilo chão* or classicism – the dominant artistic and aesthetic trend of the time in Portugal – the emphasis was placed on the architectural elements, which were fundamental not only to stability of the construction but also the only aesthetic and ornamental elements of the building.

Even in such a small city, suppliers were diverse, albeit mainly local. Some materials – i.e., those that do not naturally exist in the region and others possibly due to variation in quality – were purchased from outside the region.

From other documents and material remains, we know that the architectural project followed the model implemented by other Confraternities of Mercy – an architectural complex formed by the church, sacristy, meeting room and ward. Namely, the church replicates the characteristic planimetric design used by the *Misericordias*: one nave with a *cruzeiro* (that comprised a raised platform, as noted in the document) and a small deep main chapel (Pinho 2012), later covered by a large altarpiece. The intervention to the 16th-century House of Espírito Santo, registered in the account book of the early 17th century, did more than simply replace an old and ruined building. It also sought to remodel and expand the building so that it could serve the needs of the confraternity – in other words, the project transformed it into a veritable House of Mercy.

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History of Construction Cultures – Mascarenhas-Mateus & Paula Pires (eds)

Spatial and structural features of St Petersburg architecture in the 18th century: Transition from wood to brick

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ABSTRACT: Historical St. Petersburg (Russia) was the capital of the Russian Empire up to 1918, and now it is a city of dense historical brick architecture. However, St. Petersburg only became a brick city in the late 18th – mid 19th centuries. Before that, the majority of buildings and structures in the city and suburbs were wooden. By the end of the 18th century, 15% of buildings in total were brick, while the rest remained wooden. Starting in the 1710s, early on during Peter the Great's reign, considered prestigious (to be like European capitals) and for the fire-safety (to avoid urban fires) requirements that were directly controlled by emperors, empresses and the city administration, extreme efforts were made to forbid wooden buildings and introduce only brick structures. This received continuity by Anne and Elizabeth following the reign of Peter the Great. Furthermore, in as late as the 1760s, following decrees issued by Catherine the Great, this prohibition was implemented more actively in the areas south of the Neva river (where the imperial Winter Palace stood). It was achieved through the forced demolition of all wooden buildings and the transition to solely brick structures (including brick load-bearing walls but retaining an effective system of wooden structures already developed by that time: wooden pile fields, floorings with wooden beams, roofing structures with wooden trusses and rafters). As an intermediary result of this campaign, the transition to brick housing was completed only on the Admiralty side, namely in the area between the Neva and Fontanka rivers, by the early 19th century.

1 INTRODUCTION

Nowadays, historical St. Petersburg (Russia) is a city of dense brick architecture. However, St. Petersburg only became a brick city late in the 18th – mid 19th centuries. Prior to that, the majority of buildings and structures in the city and suburbs had been wooden. Up to the end of the 18th century, merely 15% of buildings were made of brick, and the majority (85%) of buildings and structures were wooden. In the harsh conditions of early St. Petersburg, the choice of wooden architecture was predetermined by its environmental friendliness and the possibility to erect buildings and structures at any time of the year. The more so as virtually all Russian residents were good at wood processing. Special structural systems that distinguished them from traditional Russian structures were developed for space planning in St. Petersburg.

Starting from 1703, the city and its suburbs were developed over dense swamps. Hence, for all types of buildings and structures, stone and brick foundations with wooden piles from pine, spruce and larch logs with a length of 6–8–12 meters, driven into the soil at a pitch of 30–40 cm (traditionally, St. Petersburg requirements set out the distance of not more than the diameter of the piles) were the most common, which made it possible to make a rather solid base out of swampy ground. Such a monolithic-type pile field was constructed either as a single line along the foundation or, in the case of unique buildings, as a solid field across the entire construction footprint.

Wooden buildings were erected from wooden constructions, which often displayed standard dimensions: walls (from logs and beams, as in Russian villages), floor slabs (using wooden beams), and roofing (using multi-meter wooden rafter systems or wooden trusses). The types of wooden structures developed primarily in the first half of the 18th century remained up to the beginning of the 20th century. The typology of wooden internal structures was enlarged as new types of buildings consistently appeared in the 19th–20th centuries. The architectural finish of the facades and the interior often corresponded to the style fashionable in a certain period: Baroque, Classicism, etcetera. They were also often made of wooden fittings combined with artistic designs. Many such structural and ornamental components were made outside the construction site, and the building's pieces were then put together on the construction site as if LEGO structures while undergoing adaptation to mainstream fashions and the tastes of the customer. This all allowed for fast "assembly" and "disassembly" of even enormous buildings that consisted of hundreds of halls and rooms. Many travellers who visited St. Petersburg were surprised at such movements of palaces and houses. It was especially common in the first half and –mid 18th century when, in the search for and implementation of the most optimal space-planning system of avenues, streets

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and squares, new streets were made across developed neighborhoods with existing structures dismantled and moved to new sites.

As the city and its outskirts grew, the number of wooden buildings and structures consistently reduced as they were replaced with large-scale brick constructions. However, internal wooden structures remained in active use in these brick constructions.

2 METHODOLODY

Our study, and the resulting article, rest upon the author's results of using comprehensive historical, archival, cartographic, and morphological methods of studying all St. Petersburg temples existing nowadays. Several lines can be distinguished in the process of persistent transformation (reconstruction) of the existing housing of St. Petersburg, its outskirts and suburbs from wooden to brick buildings: 1) state regulation of the location of wooden and brick housing and consistent implementation of these regulations; 2) development and implementation of special designs of housing. At the time, they were called "model designs"; 3) development and implementation of special buildings and structures to be used unconditionally. This article deals with the first line of Russian state activities for the implementation of this program.

3 RESULTS AND DISCUSSION

In as early as the 1710s, during the reign of Peter the Great, there were first attempts to prohibit wooden residential and public structures and replace them with brick buildings. This was done to meet prestige (as in Europe) and fire-safety (to avoid urban fires) requirements. Many brickworks and tile works were built around St. Petersburg. After the death of Peter the Great in January 1725, this line of housing requirements was continued by Empresses Anne (who ruled during the 1730–1740s) and Elizabeth (who ruled from 1741 to 1761). Since the 1760s, after the decrees of Catherine the Great (Empress from 1762 until 1796), this prohibition started to be actively implemented through the forced demolition of all wooden buildings and transiting to brick architecture in the area between the Neva and Fontanka rivers.

Up to 1712, St. Petersburg developed traditionally in keeping with Russian cities. Such cities had winding streets, curvilinear blocks and one- to two-story residential and public buildings in each area, where the fence entry gates faced the street's boundaries.

Peter the Great's decree issued in 1712 prohibited such constructions in the city and its numerous suburban settlements. Hence, a search for new construction options started. From then on, many space-planning features and specifics, new for Russian urban development and characteristic of regular cities, were incorporated into the design processes: linear streets (since 1712), square blocks of buildings (1712), square segmentation into sections with special dimensions (1712), closure of the most important landscape axes with vertical landmarks (since 1714), the standardization of housing in sections on the basis of "model designs" (since 1712–1714).

Figure 1. Measurement of Kotlin Island by the canal and sections. 1712. St. Petersburg. Research Department of Manuscripts of the Library of the Russian Academy of Sciences. Collection of handwritten maps. Main list No. 754.

Domenico Trezzini, a military engineer, suggested creating an enormous city with a completely new layout and shapes in the first project of this new series of space-planning designs in St. Petersburg and its suburbs, i.e., in the project for the planning and development of Kotlin Island (1712) (Luppov 1959, Murzanova et al. 1961, Sementsov 2011b). This project intended to create a regular city but with enormous dimensions of 9.4 x 3.5 km. It included the main longitudinal straight avenue (with a width of 80.0 m) with a canal and three other straight avenues without canals (having widths of 60.0 m each) running parallel, with 61 transversal streets perpendicular to the main avenues (each with a width of 60.0 m). The whole network of perpendicular avenues and streets created 226 blocks of buildings with the same width but with different lengths, depending on their location on the island and relative to the topographical conditions of access to the coastline of the Gulf of Finland. Standard blocks of buildings in the central longitudinal area of the island with two longitudinal avenues were meant to take on the dimensions of 46 x 216 sazhens ($\sim 100.0 \times 470.0$ m). The blocks were expected to be double-sided (with the division of land along both sides of the longitudinal axis of the blocks) and the project included 20×2 sections with standard dimensions of $10–11 \times 23$ sazhens ($21.60–23.80 \times 50.0$ m). There were 7278 sections in total.

The requirements (regulations) for construction of residential and public buildings, whether using brick or wooden structures in developed areas, were designed and approved by imperial decrees for St. Petersburg and its suburbs by 1718. The following system applied to implement these requirements was developed and rigorously followed: the Directorate of Police (responsible for construction in the city and its suburbs) issued a "model design" (what and how could be built on a plot) to the plot's future owner (Figure 1).

Figure 2. The "model" St. Petersburg. 1718. Development of the city-planning fabric. City-planning regulation of layouts and housing (according to design and legal materials) (reconstructed by architect S.V. Sementsov).

Figure 3. The "real" St. Petersburg. 1761. Formation of the city-planning fabric (reconstructed by architect S.V. Sementsov).

This specifically pointed out that only brick residential buildings (highlighted in red in the diagram) could be built along the red lines of streets, and only wooden buildings — along other streets. This required construction to be finished within five years. However, when the plot owners faced with the brick residential building requirement along the red line did not have the necessary number of bricks and could not acquire them within a year, the owner was permitted to build residential wooden structures on the plot but not along the red line of the street and deep within the boundaries of the plot. Such structures could only be temporary, with a requirement to build a brick residential building in the years to come (Ageyeva 1999; Nikolayeva 2014; Sementsov 2000).

Brick buildings would be built according to the regulations using a "model design" of a two-story brick building produced by the French architect, Jean-Baptiste Alexandre Le Blond, in 1716. Wooden buildings would be built according to the regulations using a "model design" of a one-story house (with a mezzanine) designed by an Italian military engineer, Domenico Trezzini, in 1712–1714.

From November 1721, after the victorious end of the war against Sweden, the Russian state was declared the Russian Empire, and Peter the Great solemnly proclaimed the Russian Emperor. The matter of completing all construction works became of utmost importance in order for St. Petersburg to reach the status of the Russian capital. Peter the Great demanded the finishing of all construction works carried out in St. Petersburg (primarily on Vasilyevsky Island) and its suburbs by January 1, 1726. However, the works were not finished by the date stipulated by the Russian emperor. Peter the Great died in January 1725, and the era of stagnation started. It only ended in as late as 1731 (Figure 2).

Anne (Algarotti 2014; Anisimov 2002) and Elizabeth (Coughlan 1974; Anisimov 2005) reigned after the death of the emperor. They also carefully followed these requirements. Moreover, in their management of the reconstruction and development of St. Petersburg in new territories, their imperial decrees demanded not only compliance with the brick construction requirements for historical areas of St. Petersburg but also compliance with the same requirements in newly built territories and, therefore, expanded the potential territories subject to brick construction.

However, by 1761, the overwhelming majority of structures in the city and its suburbs were wooden. Even many palaces and mansions in the city were built of wood in the Baroque style with splendor and multiple carved and gilded fittings. There are many archival and iconographic documents of that time demonstrating this. These documents include the famous multiple-page "Layout of St. Petersburg" made in 1764–1773 with the guidance of Pierre-Antoine de Saint-Hilaire by masters I. Sokolov, A. Gorikhvostov and others (Mazur 2003) (Figure 3).

The assumption of power by Catherine the Great did not change the general direction of the mandatory targeted requirements set out in imperial acts and the whole system of city-planning regulations, as well as in the system of implementation and supervision of city-planning, architectural and construction activities in St. Petersburg, maintaining the general direction

Figure 4. NEW LAYOUT OF THE CAPITAL CITY AND FORTRESS OF ST. PETERSBURG. The original drawing of the layout is kept in the archive of the Directorate of Police. C.M. Roth. 1776. St. Petersburg. Russian National Library: *к* 1-П6 2/10.

Figure 5. Layout of the capital city of St. Petersburg dd. 1796. St. Petersburg. Russian State Archive of the Russian Navy. Fund 1331. List 1. Case 194.

of transition from dense wooden to dense brick construction (Brikner 2004; Chistyakov & Novitskaya 2000–2001; De Madariaga 2002; Gribovsky 1989).

Her imperial decrees primarily required an unconditional transition of all buildings and structures on the Admiralty side of the Neva river (along the Admiralty, Palace and English Embankments) to the Fontanka river (the southern border of the city at the time) from wood to brick. All the General Layouts included these requirements. For instance, the General Layout of 1776 defined areas with different regulated (mandatory) types of designs: only brick structures (Type I), brick structures along the red lines (facades) with wooden structures deep within the boundaries of the land plots (Type II), wooden structures with stone cellars (Type III), and wooden structures (Type IV) (Figure 4).

Subsequently, in the General Layout of 1786, produced during the first year of the reign of a new emperor, Paul I, the requirements were also extended to the urban territories on Vasilyevsky Island. This Layout described the requirements for brick buildings (downtown) and wooden buildings (on the periphery and in the outskirts) (Figure 5).

At the beginning of the 19th century, in 1801, the territories with all wooden or primarily brick buildings and structures expanded. They included: the territories

Figure 6. The "real" St. Petersburg. 1801. Formation of the city-planning fabric (reconstructed by architect S.V. Sementsov).

from the Neva to the Fontanka rivers (almost a dense field of brick buildings), along the embankments of the Neva river on the Admiralty side, on Vasilyevsky Island, on the Spit of Vasilyevsky Island, and individual main avenues south of the Neva river (Sementsov 2011a). However, as follows from analysis of the formation of the city-planning fabric of St. Petersburg, hardly any of the residential and public areas in the territories intended for development were entirely filled with brick buildings.

These processes of reconstructing wooden buildings with brick structures continued into the 19th–early 20th centuries (Figure 6).

4 DISCUSSION

For the first time in the historical and city-planning studies of St. Petersburg, this article sets out the consistency and steadiness of the actions taken in the 18th century and intended to dramatically convert St. Petersburg from a traditional Russian wooden city into a brick capital city.

5 CONCLUSIONS

The author has identified an unusual system developed and implemented by the Russian and St. Petersburg authorities to create forced large-scale brick housing in St. Petersburg and thereby departing from the wooden housing traditional to Russian cities. These processes ran parallel to the process of building an enormous regular city.

6 RECOMMENDATIONS

This article can be recommended to historians studying city-planning and architecture, specialists in protection, conservation and restoration of historical and cultural heritage, city planners, architects, urbanists, designers dealing with the matters of the development of modern cities and urban agglomerations as well as the preservation of historic cities and landscapes.

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History of Construction Cultures – Mascarenhas-Mateus & Paula Pires (eds)

Transition from wood to iron in French theatre structures: A new construction system

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ABSTRACT: In the second half of the 18th century, France was a significant centre for the use of wrought iron in civil architecture. Due to the promise of fireproof constructions, theatres were among the first to incorporate the new material, since iron was believed to be more resistant than timber. Many ideas and architectural proposals emerged, aiming to improve theatre design and construct robust, fire-proof structures. In particular, an innovative construction system combining wrought iron trusses and fillings of hollow pots was proposed in the 1780s. This article focuses on the transition to iron in Parisian theatre roofs and on the application of this new construction system. The contribution of theatre structures in the application of iron and the development of “fire-proof” trusses is highlighted through archival plans and preserved examples.

1 INTRODUCTION

In 18th-century France, new ideas and innovative techniques were introduced in construction. The urban landscape was redesigned with the construction of prestigious buildings. Several design projects including theatres changed the appearance of large cities and numerous private residences were erected.

Theatre structures underwent constructional and technical upheaval, first induced by social conditions and gradually supported by technical and scientific progress.

1.1 *Theatres in France during the 18th century*

In the first half of the century, a lack of specialized structures was evident in the French capital as well as in the provinces (Fuchs 1933). Few theatres constructed before 1700 existed in Paris. Some were attached to a palace, such as the Opéra du Palais-Royal (1639) and the Salle des machines in the Palais des Tuileries (1662). Others were refurbished existing structures, including the Hôtel de Bourgogne (1548), and the Salle de la rue des Fossés-Saint-Germain-des-Près also called Jeu de paume de l’étoile (1689). Those performance halls, however, were roughly adapted to the contemporary needs (Rabreau 2008). Remarkably, during the first half of the 18th century no theatres were constructed in Paris.

The evolution of theatre construction started in the French province (Figure 1). Those early performance halls were specifically designed to respond to particular requirements such as the Comédie d’Avignon (1734), the Théâtre de Metz (1752) and the renowned Salle de Spectacles in Lyon (1756), constructed by Jacques Germain Soufflot.

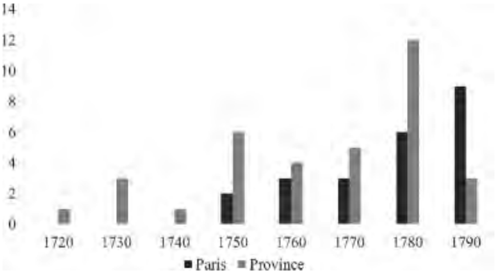

Figure 1. Theatre construction in Paris compared to the French province from 1720 until 1790 (data: Chalvatzi 2020b).

In the second half of the 18th century, theatre construction blossomed. Performance halls evolved into representative structures within the urban tissue. In addition to this architectural evolution, theatres showcased a structural development in order to respond to the larger spans, the complex machinery above the stage and the subsequent heavy loads. The spans nearly doubled in a few decades: from approximately 14 m in the Salle de Spectacle in Lyon (1756) to 23.5 m in the Grand Théâtre in Bordeaux (1780).

After 1750, numerous theatre projects were constructed with interesting timber roofs, three of which are briefly presented here. The reconstruction of the Opéra du Palais-Royal after the fire of 1763 was assigned to the architect Pierre-Louis Moreau-Desproux (1727–1793). The performance hall was inaugurated on 26 January 1770 (Dupézard 1911). The theatre’s roof was a timber purlin structure with innovative elements, including iron queen posts and a polygonal arch connecting the straining beams (Krafft 1820).

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Figure 2. Cross section of the roof of the Opéra Royal in Versailles (Survey plan: author).

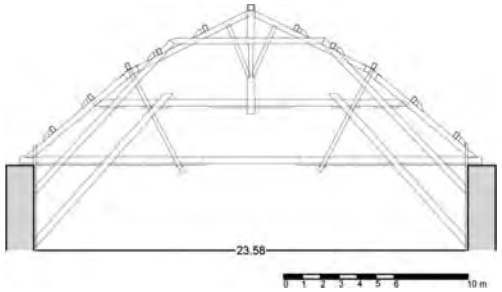

Figure 3. Cross section of the roof of the Grand Théâtre in Bordeaux (Survey plan: author).

The design of the Opéra Royal in Versailles was started in 1763 by the architect Ange-Jacques Gabriel (1689–1782) and the theatre was completed in 1770 (Mercure de France 1770). The structure of the roof was finalized in 1769 and is completely different from the simultaneously built Opéra du Palais-Royal. It is a timber purlin structure with a span of 20.45 m. It has a king post and two queen posts, and rafters that form an uncommon subordinary structure with the braces, which are doubled and connected to them with perpendicular struts (Figure 2).

A further significant theatre project is the Grand Théâtre in Bordeaux, designed by the architect Victor Louis (1731–1800) from 1773 to 1780. A milestone in theatre construction, this performance hall is crowned by a unique mansard purlin timber roof, which comprises a king post, a tie-beam and a collar beam. Instead of queen posts, each truss has an interlocking combination of two sets of doubled diagonal braces and hangers (Figure 3). The clear span of the structure is equal to 23.58 m.

These consecutive innovative structures highlight the constant effort to integrate demanding requirements into the design of the roof.

Figure 4. Fire accidents in French theatres from 1640 until 1940 (data: Chalvatzi 2020b).

1.2 *The danger of fire*

In the 18th century, numerous performance halls were erected in provincial cities, and also in Paris after 1750. The frequency of fire accidents followed the growth of theatre construction (Figure 4). Over the course of the 18th century, destruction by fire became a critical factor in theatre roof construction. Several proposals emerged that addressed both construction materials and architectural design. The latter included the size of corridors, staircases, the method of evacuation, the separation of the stage from the auditorium and the addition of water tanks. The discourse about protection from fire extended to the selection of specific construction materials. Consequently, alternatives to wood were proposed to promote robust construction.

The first ideas designed to replace wood included the construction of masonry vaults (Neufforge 1768, Chaumont 1769, Dumont 1775), which did not fulfil the acoustic requirements of performance halls (Patte 1782). In addition to the existing proposals for fireproof construction (Espié 1754), a further idea, specially developed for theatres, was to utilize iron in the construction of roofs (Ango 1785a).

2 IRON ROOFS IN 18TH-CENTURY FRANCE

2.1 *A new construction system*

After the completion of the Grand Théâtre in Bordeaux, Victor Louis was assigned the refurbishment of the Palais-Royal, including the reconstruction of the theatre attached to the palace, which had been destroyed by fire in 1781. The new theatre of the palace was erected between 1787 and 1790 at the corner of rue de Richelieu and Montpensier. The roof of this performance hall, which comprised of wrought iron trusses and fillings of hollow pots (Figure 5), had the shape of a barrel vault with a span of approximately 23.9 m. Hollow pots were lightweight ceramic elements with a rectangular top and a round base. The roof of the Théâtre-Français became renowned in contemporary publications and more recent literature (Bannister 1950; Rondelet 1816).

Each truss had two superimposed arches and a horizontal iron tie, which were secured with a vertical suspension element in the centre, a diagonal hanger and four diagonal struts on each side. This construction was based on the publications and experiments of Jean Far Eustache de Saint-Far (1746–1828) and Jean-Pierre Ango (1739–1815). Saint-Far presented his proposals for vaults made of hollow pots at the Académie Royale d'Architecture in 1785 (Lemonnier 1926). Some of his experiments included the application of iron reinforcements (Lacombe 1791) to masonry vaults. Ango, on the other hand, focused his experiments on the design of iron fire-proof floors and roofs (Ango 1785a), which he presented to the Académie in 1782 (Lemonnier 1926).

The application of this construction system at the Palais-Royal was probably a result of collaboration between Victor Louis and Abbé Baudeau (1730–1792?), who was the founder of the Société Libre d'Emulations (Nègre 2016). Before the construction of the large theatre, the architect applied this system to other parts of the palace (MS 51). The restoration of the palace by Pierre-François-Léonard Fontaine (1762–1853) from 1814 to 1831 was based on the existing iron and hollow pot roofs.

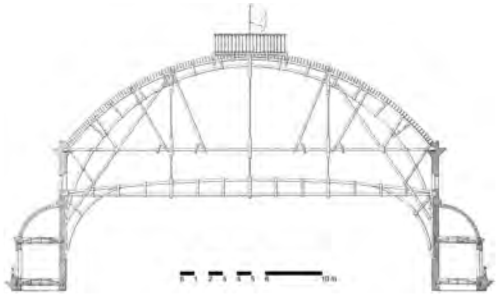
Figure 5. Cross section of a truss of the Théâtre-Français showing the fillings of hollow pots (Eck 1836).

Although large parts of the Palais-Royal were added by Fontaine or thoroughly refurbished, some original parts were preserved during the restoration of 1830 (Fontaine 1987). As a matter of fact, the Montpensier wing is entirely covered by iron roofs, most of which were constructed by Fontaine and Pierre Prosper Chabrol (1812–1875).

The famous iron and hollow pots roof of the Théâtre-Français was entirely destroyed by the fire that ravaged the theatre on 8 March 1900. Until now, the study of early French iron application in theatres has been examined exclusively based on archival plans.

2.2 *A second theatre with an iron roof at the Palais-Royal*

Besides the Théâtre-Français, Victor Louis constructed a small performance hall at the north-western angle of the arcades of the Palais-Royal. This structure, today called the Théâtre du Palais-Royal, was completed in 1785 (Figure 6). There is, however, very little information about its construction process (Chalvatzi 2020a).

The façade of the theatre, which consists of cast iron walkways, does not prepare the observer for the innovation of the interior structure. The auditorium and lateral foyer preserve the decoration of the late 19th

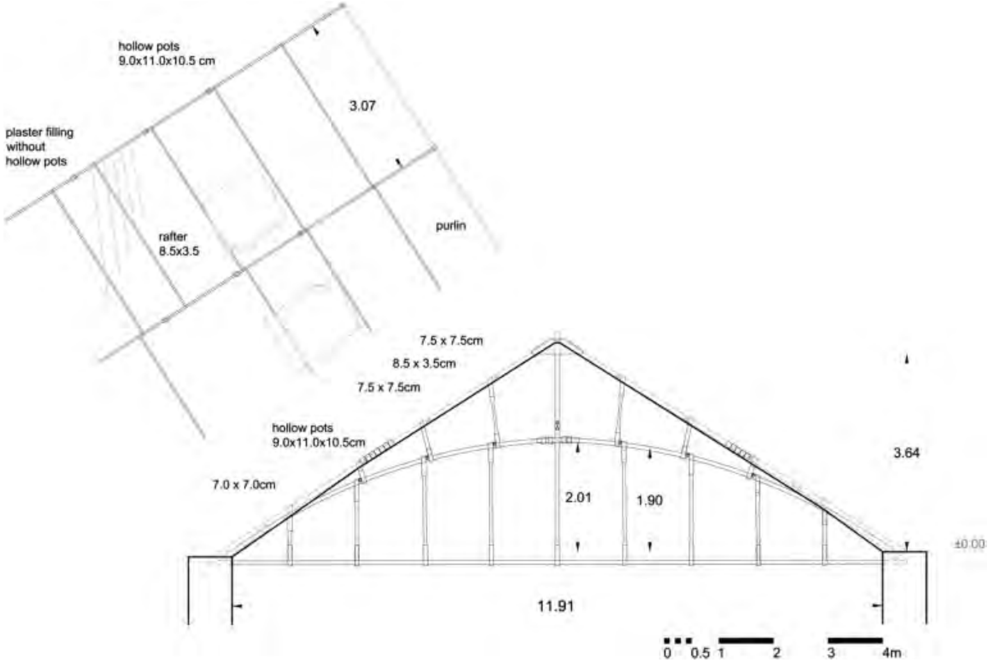

Figure 6. Cross section of the roof of the Théâtre du Palais-Royal with a reclination of the longitudinal section (survey plan: author).

century. However, the roof of this theatre is constructed in wrought iron and hollow pots. As was the case in the Théâtre-Français, the hollow pots are used for the fillings between the trusses.

Each truss consists of a twelve-metre-long horizontal tie resting on the lateral walls, two rafters extending from the horizontal tie to the highest point of the roof, and a king post in the middle of the truss that connects the ridge to the horizontal tie, as well as a bipartite arch connecting the supports with the king post. The arch is connected to the horizontal tie with eight vertical secondary posts and to the rafters with three braces on each side. The rafters and the arch are elements under compression, which is confirmed by the assembly details. The vertical posts work in tension and relieve the stresses of the horizontal tie.

The assembly details of the elements in tension are very particular. The connections between the horizontal tie and the arch as well as those between the arch and the rafters are variations of the same principle: wrought iron fasteners envelop the horizontal and the vertical element, and are fixed with hammered pins. These pins are a sort of rivets that are shaped by cold hammering; the traces of the assembly are thus not similar to typical rivets. The connections are welded and the rivets are hammered from both sides, leaving visible traces on the material's surface.

The combined study of the two theatre roofs constructed in the Palais-Royal exemplifies the application of the construction system with iron and hollow pots. Nonetheless, the two structures are different form each other mainly due to their different scale. In the case of the small theatre, the span is equal to 12 m and the structure is a pitched roof, with a similar design to Ango's plan published by Rondelet in 1816. The roof of the Théâtre-Français was a barrel vault with a 23-m span. The roof frames comprised arches, one of which functioned as a rafter and purlins. Diagonal elements provided stabilization, working under tension or compression depending on their position at the truss. The design of this structure is not based on previous timber roofs and thus seems remarkably novel. It is probably a result of the evolution of this particular construction system, which started out as reinforced vaults made of hollow pots, according to the aforementioned proposal from Saint-Far. In both cases however, the wrought iron frames were combined with hollow pots embedded in plaster to achieve fire protection.

Regarding an understanding of the construction system with iron and hollow pots, the roof of the Théâtre du Palais-Royal is crucial, as it allows hands-on observation of a preserved structure.

3 THEATRES WITH IRON ROOFS IN THE 19TH CENTURY

The last decade of the 18th century was characterized by political instability and a shift in social ideas. The French Revolution influenced not only the evolution of construction techniques and materials, but also theatre construction, which diminished significantly during that time (Steiner 1984). The demand for military iron rose, impeding its application in civil structures (Woronoff 1982). The fire-proof construction system with iron and hollow pots was temporarily put on hold. The few theatres constructed during that time had timber roofs, including the Opéra de la rue de Richelieu (1793), designed by Victor Louis (Kaufmann 1840).

3.1 *Revival of the construction system*

After the 1820s, the erection of performance halls increased, in particular in the French capital. During this decade however, theatres again became the centre for the application of iron, without eradicating timber construction. This time was thus marked by the application of the new material in combination with hollow pots.

Gradually several theatres in Paris, both new and reconstructed, were crowned with iron roofs (Figure 7). None of the original structures are preserved, but their study through published and archival plans throws light on the second attempt to apply wrought iron in Parisian theatre roofs.

The Théâtre des Variétés (1827) was an early example of the application of the wrought iron and hollow pots system, designed by the architect François Debret (1777–1850) (Figure 7A). The wrought iron structure of the roof had the shape of a barrel vault and a span of approximately 16 m. It comprised a composite horizontal tie, an arch, diagonal struts and vertical posts. (Eck 1836).

In parallel to the Théâtre des Nouveautés, the Cirque Olympique was constructed in 1827 by Alexandre-Benoît Bourla (1792–1850) (Figure 7B). The wrought iron and hollow pots structure of the roof was different above the stage and the auditorium and had a span equal to 18 m; both parts had an ogival shape and comprised two superposed arches, two horizontal ties, diagonal struts and hangers (Kaufmann 1840).

The Théâtre de l'Ambigu-Comique (1828) was erected by the architects Jacques-Ignace Hittorf (1792–1867) and Jean-François-Joseph Lecointe (1783–1788), (Figure 7C). The roof, which had a span of approximately 17.5 m, had the shape of a lancet arch and consisted of wrought iron and hollow pots. Each truss comprised a bipartite arch, a tie-beam, two collar ties and vertical struts. The tie-beam was composite and so were the arches. The structure had a king post extending between the ridge and the tie-beam and four vertical posts between the arches and the tie-beam providing stability (Eck 1836).

Among the theatres constructed with wrought iron and hollow pots, the Salle Ventadour (1829) was very renowned for its monumentality (Figure 7D). Erected by Jean-Jacques-Marie Huvé (1783–1852) and Frédéric-Louis Regnier Marquis de Guerchy (1784–1832), this theatre was intended for the Opéra-Comique. The roof, with a span of approximately 20 m, had an ogival form. The trusses over the stage and the auditorium were probably not identical, in order to serve different functions. Each truss over the auditorium consisted of two composite arches, a horizontal

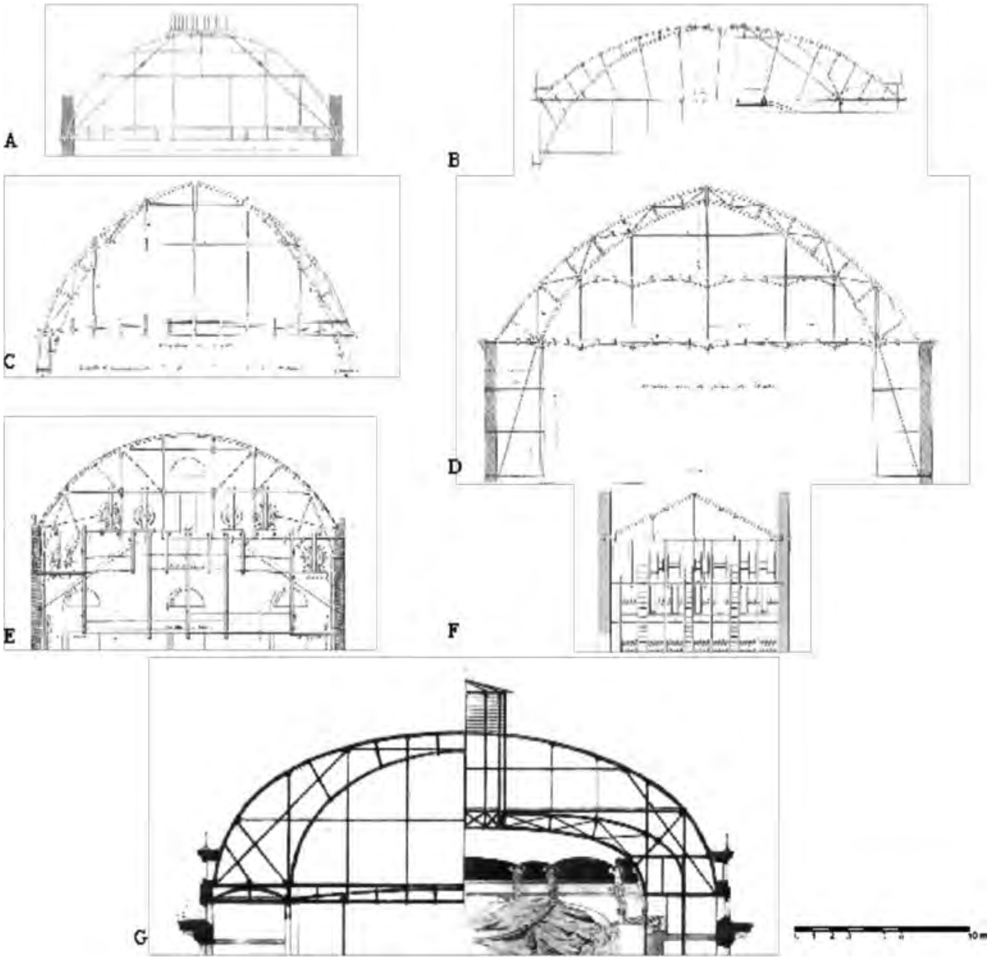

Figure 7. Parisian theatres constructed with iron roofs from 1827 until 1840: A. Théâtre des Variétés (1827), B. Cirque Olympique (1827), C. Ambigu-Comique (1828), D. Salle Ventadour (1829), E. Théâtre de la Gaîté (1835), F. Théâtre Saint Marcel (1838), G. Salle Favart (1840) (Eck 1836, Kaufmann 1840, Bibliothèque Nationale de France).

tie, two collar beams and vertical posts (Eck 1836). The horizontal tie and the lower collar beam were reinforced with several small arch elements to reduce deflection.

After 1830, theatre roofs in Paris were essentially constructed in wrought iron and hollow pots. The Théâtre de la Gaîté was erected in 1835 by the architect Alexandre-Benoît Bourla to replace a previous theatre with the same name (Kaufmann 1840) (Figure 7E). The roof of the performance hall had the shape of a barrel vault and a span of approximately 18 m. As was the case for many theatres of that time, the trusses above the stage were not identical to the ones over the auditorium. Each truss had an arch, a horizontal tie, two collar beams, four vertical posts and diagonal trusses. On the level between the horizontal tie and the collar beam there were two diagonal struts suspending the horizontal tie and two diagonal struts, which rested on the lateral walls, supporting the collar beam. The trusses did not have central king posts. Hollow pots were applied in this structure for the separating wall between the stage and the auditorium and for the construction of smaller vaults.

A smaller structure in comparison to the rest of the theatres described, the Théâtre Saint-Marcel, was constructed in 1838 by the architects Ed. Lussy and Maurice Allard (Figure 7F). The design approach for the roof of this performance hall was unusual. The structures above the stage and the auditorium were extremely simple pitched roofs. The particularity of this roof consisted in the placement of the structure over the stage: the trusses were spanning in the longitudinal direction, because this span was shorter than the width of the cross section and equal to 12 m. The axis of the structure was thus rotated 90° in comparison to other theatre roofs. This was a rare example of a pitched roof of that kind, most certainly chosen due to the small span (Lussy & Allard 1840).

In 1849, the second Salle Favart was constructed by the architect Louis-Charles-Théodore Charpentier

(1797–1867). This new theatre replaced the previous one on the same building plot after a fire on 14 January 1838. This destruction raised questions about the construction of the new theatre and the methods for fire protection (Soubies & Malherbe 1887). The roof of the new theatre was constructed in wrought iron and had an elliptical shape. Probably due to the machinery requirements, the trusses above the stage were very different than the ones over the auditorium. Over the stage, the trusses had a rafter that was forming the exterior surface, two collar beams and a second lower arch that was resting on the interior walls of the performance hall. The rafter and the arch were connected with diagonal struts. The trusses over the auditorium had simple elliptical rafters that formed the exterior surface of the roof. The ceiling of the interior comprised of a composite arch, which consisted of two elements connected with intersecting diagonal struts.

None of these theatres are preserved. As a result, the study of early 19th-century wrought iron theatre roofs is based on archival and published plans, leaving numerous questions concerning assembly, detailing and the use of hollow pots unanswered. However, it is remarkable that not even one of them was destroyed by fire.

3.2 *Evolution of the construction system with iron and hollow pots in the 19th century*

The advantages against fire of the construction system with wrought iron and hollow pots were recognized in an assessment of the Théâtre-Français in 1801 (Archives Nationales 1801). Nevertheless, the application of this system in further Parisian theatres only started around 1827.

Before the abovementioned theatres, Eloi Labarre (1764–1834) had already designed and constructed the roof of Palais Brongniart between 1813 and 1826, applying wrought iron and hollow pots (Rondelet 1830). This particular roof was different from the structure of the Théâtre-Français: the hollow pots in the roof of Palais Brongniart were not used as fillings between the roof frames, but formed a vault separating the iron roof from the interior space of the edifice.

The assessment of the plans of 19th-century theatres allows some observations on the evolution of theatre roof design at that time. The performance halls discussed here display a variety of forms and structural solutions. Apart from barrel vaults for large spans and pitched roofs for smaller ones, the applied roof shapes included lancet arches and elliptical forms to respond to particular space and load requirements.

The separation of the stage from the auditorium led to the application of different designs in the two parts. The roof frames of the stage were thus specialized for the machinery. The trusses over the auditorium incorporated the structure of the ceiling and were adjusted to the infrastructure for lighting.

The observation of the drawings of theatre roofs includes different variations of wrought iron trusses. The early solutions are similar to the roof of the Théâtre-Français, with arches and diagonal or vertical hangers and struts. In later roofs, the arches and the horizontal ties were composite. The arches were doubled with vertical struts and the horizontal ties comprised smaller strengthening arches.

The evolution of the design is striking in the case of the Salle Favart, where the two parts of the roof are completely adapted to the particular requirements of the stage and auditorium. The arches were doubled over the stage due to the heavy loads of the machinery, while over the auditorium the composite arch carried the weight of the chandelier.

In a similar way, the positioning of the hollow pots was also adapted to the need for fire protection. The pots were used for the construction of separating walls and vaults under the wrought iron roof, as was probably the case in the Théâtre de la Gaîté. The application of hollow pots was limited in later examples and the round pots were replaced by hollow rectangular bricks after the 1850s. The hollow pots were handmade and thus hard to standardize and mass produce.

In the second half of the 19th century, the construction system with iron and hollow pots was superseded by the prevalence of steel. Theatre roofs were still constructed from iron, but the design and the construction techniques were influenced by the growing iron industry.

4 FACTORS THAT INFLUENCED THEATRE CONSTRUCTION FROM 1780 TO 1840

Theatre construction was a fruitful field for experimentation and innovation in the late 18th and early 19th centuries. Theatre design was influenced by the political situation in France and the architectural development induced by the Académie Royale d'Architecture. Construction of theatres was reduced between 1790 and 1820, primarily because of the French Revolution and later due to the decree of 1806, which controlled theatrical operation (Grille 1817).

Fire accidents were an important factor in the evolution of theatre design. The architectural development of theatres constantly improved to respond to particular requirements. In parallel, the risk of fire enhanced the development of the fire-proof construction system with iron and hollow pots and thus the introduction of iron to theatre roofs.

The evolution of this construction method was not constant. Despite the persistently high risk of fire, theatres were still constructed with traditional materials until 1827 in Paris, and until the middle of the 19th century in the provinces (Figure 8). After 1838, the decrees concerning theatre design identified the solid, fire-proof construction of theatres as indispensable. The choice of particular construction methods or materials, which were not cited in the decrees, was left to the construction managers.

Nevertheless, the application of iron and hollow pots prevailed in Paris after the 1820s. Although the danger of fire was not eliminated by iron roofs, as of the end of the 19th century iron became the main material for the construction of theatres.

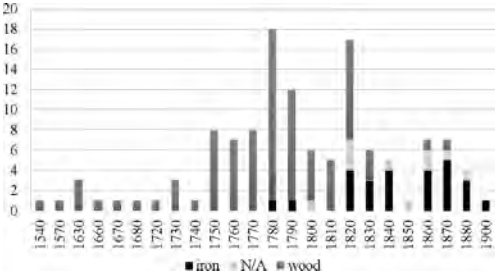

Figure 8. Theatre construction from 1540 to 1900 showing the application of timber (dark grey) and iron (black) in the roof. (Data: Chalvatzi 2020b).

5 CONCLUSION

The period from 1780 to 1840 was significant both for theatre construction and for the application of iron in civil structures. During that time, theatres evolved architecturally from mundane structures to representative and monumental urban objects. Moreover, the construction methods and the structural solutions for the roof showcase remarkable progress.

The requirements involved in the construction of performance halls led to the evolution of a construction system that aimed to protect the structures from the danger of fire and promoted the application of new materials. This led to the development of numerous structural solutions in theatre roofs made of wrought iron and hollow pots. The transition from timber to iron roof structures was marked by the application of this construction system.

Remarkably, the design of early iron roofs in Parisian theatres was not based on previous timber structures. The iron trusses were combined with vaults or roof surfaces made of hollow pots. The structural design of those early iron trusses was based on the research on iron reinforcements in masonry vaults of Jean-Pierre Ango and Jean Far Eustache de Saint-Far and their experiments.

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History of Construction Cultures – Mascarenhas-Mateus & Paula Pires (eds)

Designing a ground-breaking structure: Notes on the cast-iron/wrought-iron dome of the former Halle au Blé, 1809–1813

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ABSTRACT: Designed by F.-J. Bélanger and F. Brunet, the cast-iron and wrought-iron framework covering the former Paris wheat market was built in 1809–13 in order to replace the wooden structure designed by Legrand and Molinos in 1782–83 and destroyed by fire in 1802. Validated by the central administration, it was the first, large-diameter dome entirely built with iron elements. How was this structure able to persist as a model when its design was partly founded on empirical considerations or uncertain knowledge acquired through the construction of the first cast-iron bridges? Indeed, the sizing of the elements was based on embryonic theoretical considerations, the development of which was only completed subsequently, permitting the proper resolution of the problem of elastic curved beams. In this paper, we shall attempt to reconstitute the theoretical aspects underpinning the design of this unique structure, built well before iron framework reached an autonomous technical form.

1 INTRODUCTION

After completing a number of building, interior decoration and garden layout projects for the aristocracy, François-Joseph Bélanger was commissioned towards the end of his career to carry out two specialised studies: the roofing of the Halle au Blé (1808) and the Rochechouart slaughterhouse (1809). Only the first of these utilitarian projects was completed. Bélanger, an enlightened architect open to new ideas, was at this stage of his activity an experienced practitioner who had established close relationships with influential figures, engineers and scientists. During his successive trips to England, he had also been able to observe closely the most recent urban developments, the gardens of the most fashionable architects, and some of the technical achievements characterising the industrial landscape on the other side of the Channel. His project for a new dome for the Halle au Blé (wheat market), his first and long awaited public commission, was developed in at least two stages, a first draft in 1781–82 and a second version in 1807–09. Hence, the general sketch and the subsequent construction details were developed and perfected over several years, resulting in a project characterised by a clear balance between architectural and technical form – which ultimately represented a guarantee of feasibility and longevity of the structure (Brunet 1809; Canovetti 1888; Rondelet 1803).

2 FROM THE DRAFT TO THE CONSTRUCTION DRAWINGS

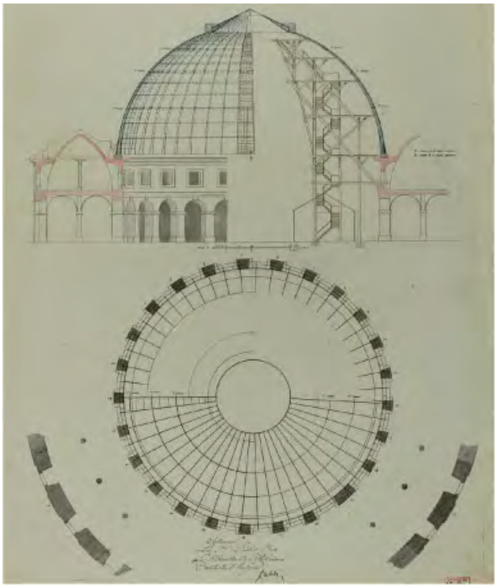

Figure 1. Plan and section of the Halle au Blé, with an outline of the scaffolding. Hittorff coll., H.B. 008, Wallraf-Richartz Museum. Ph. D. Bongartz.

The hemispherical dome is based on a scheme with meridians and parallels. According to the design by Bélanger and François Brunet (appointed works inspector on the dome site), its structure, which rests on the pedestal at the top of the inner wall of the hall, consists of an array of 51 large, curved trusses (meridians) held together by struts forming 15 circular girdles (parallels) (Figure 1). Each truss consists of 5 voussoirs of variable length bolted together. The four girdles located at the joints between the voussoirs are

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called junction girdles, and the other girdles are known as uniting girdles. The general sketch of this framework stems from immediate geometrical and formal considerations and respects the fundamental principles of architectural composition of the French classical revival. In this respect, the reminders made by Viel in his *Dissertations* on questions of order and on the proportions to be adopted are exemplary: "I conclude by proposing that the Commission decide that the height of the new dome should be that of its diameter, with a single opening at the top" (Viel 1809).

The intrados of the trusses is drawn along a circle with a radius of 19.63 m and the extrados along a circle with a radius of 20.20 m, the centres of these circles being vertically 32 cm apart. As a result, the height of the cross-section of the trusses decreases from the base to the top of the dome. The height of the cross-section of the struts is dictated by the height of the trusses at the meeting point of the girdles and trusses. Thus, the height of all the elements, voussoirs and struts, was directly derived from the architectural sketch and could no longer be modified. For the correct sizing of the structure, all that remained to be determined was the cross-sectional area of these elements, or, more specifically, their thickness, since the static height was known. According to this reading, and disregarding uncertainties in the general static scheme linked to the possible modelling schemes for internal joints and connections, calculating the cross-section of the elements was, therefore, a matter of determining their thickness, which was set at two and a half inches (6.8 cm), decreasing slightly from one voussoir to the next going upwards. The thickness was also subject to certain constraints linked to the melting operations of the cast iron.

With regard to the structural aspects, it is reasonable to assume that the considerations and results used to size the elements – i.e. to determine the minimum or sufficient cross-section of each voussoir or strut – were preceded by a test campaign carried out on samples of metallic materials and full-scale models. They were also no doubt based on the data already available on the resistance to compression and bending of wrought-iron or cast-iron parts or stone voussoirs of comparable size. Indeed, Bélanger succinctly mentions these models many times in letters addressed to the Ministry of the Interior requesting reimbursement for the manufacturing expenses incurred (Bélanger 1811).

2.1 *The Report of Becquey de Beaupré*

One of the most significant documents concerning issues of general design and choice of materials is, undoubtedly, the final report written in July 1807 by the chief engineer of the Ponts et Chaussées of the Seine department, S. Becquey de Beaupré. Becquey makes detailed comments on the version of the project initially submitted by Bélanger, and expresses that he is in favour of the construction of a metal structure, "composed of vertical arches in molten iron linked by wrought-iron struts" (Becquey de Beaupré 1807). On the basis of the indications provided in this document, some of which are based on economic arguments, the project evolved to acquire an entirely new general appearance, which was to become final.

One of the subjects most debated by the members of the commission was that of the most suitable material from which to manufacture the large trusses and struts of an all-metal dome, particularly since the project, which seemed to coalesce the preferences of the majority, did not provide a sole answer. It evaded the choice between wrought iron and cast iron, which were described as equivalent or both presenting advantages and disadvantages. The question of element thickness marked a turning point in the debate. According to Becquey, in particular, the large trusses had to be 30 lines (6.8 cm) thick at the bottom, 18 lines (4.1 cm) thick at the top and 24 lines (5.4 cm) thick in the middle. The first consequence of this modification was a significant increase in the manufacturing cost of the wrought-iron components. However, according to Becquey, this increase in thickness could be obtained "not only with no increase, but actually with a decrease in cost; this could be done using molten-iron instead of wrought-iron arches". Using heavier members does indeed make it possible to abandon the pottery fillings planned by Bélanger to consolidate the lower caissons of the dome. According to this scheme, only the reinforcing frames meant to correspond with junctions between truss parts would ultimately be made of wrought iron.

The first time Becquey made the connection between the building of the dome and that of the recent Austerlitz Bridge was with regard to the cost of manufacturing models for the preparation of casts and the cost of adjusting and lifting trusses. Evaluating these expenses, by comparing the two projects, allowed him to determine the savings which would result from the use of cast iron for the dome trusses. Becquey determined that the bridge voussoirs, which were 5 feet (1.62 m) long and 4 feet (1.3 m) wide, with 21 voussoirs for a simple single span arch, had required manufacturing 12 models (excluding strut models), whereas manufacturing one dome truss, supposedly divided into four parts, would not require more than four models. According to Becquey's estimate, the cost of the dome models would be at least one third less than the cost of the bridge models.

The successive points listed in Becquey's estimate make it possible to measure the influence of his report on the commission's decisions and on the final design of the dome. It was, indeed, the chief engineer of the Ponts et Chaussées who clearly indicated the technological solutions to be included in the dome project (some of which have already been adopted for the Austerlitz Bridge): "The author has not proposed using copper in the assemblies; but I do not believe that we can do without at the junction of struts against arches …". It is, therefore, Becquey's report that led to considering the addition of copper shims between the facets of all the dome assemblies.

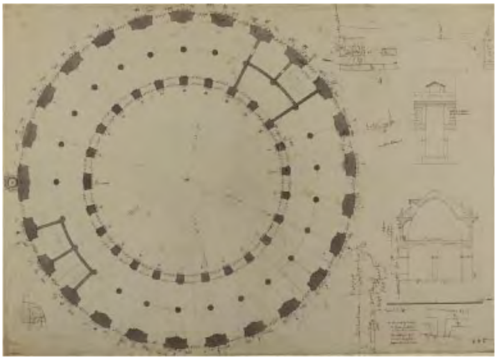

Figure 2. Survey with dimensions showing the irregularities of pillars and openings. Hittorff coll., H.B. 005, Wallraf-Richartz Museum. Ph. D. Bongartz.

The question of the most suitable material for the manufacture of horizontal struts was also one of the most widely discussed topics by the commission members. As we have seen, the material chosen for the vertical arches was cast iron, for which Becquey had expressed a preference. On the other hand, wrought iron was initially chosen for the horizontal struts. However, this early choice was the result of a mistaken evaluation.

Becquey believed that the vertical arches had to be aligned with the arcades below. However, if the vertical arches were to be aligned with the axis of pillars or the axis of openings, the irregular spacing between pillars of arcades would lead to a lack of regularity in the layout of the dome trusses (Figure 2). Thus, the priority given to this alignment meant that the dome grid lost some measure of regularity. This was the basis for the proposal to adopt wrought iron for the horizontal struts. The unequal division of the base of the dome by vertical arches perfectly aligned with the arcades would result in struts of varying length; if they were made of cast iron, these very diverse elements would have required a large number of different models, resulting in higher manufacturing costs. Hence, Becquey's initial choice to use wrought iron for the struts. This option, which meant a dome with a slightly irregular grid, was, of course, abandoned.

The number of parts making up the large curved trusses was also the subject of extensive debate among commission members. Being at the crossroads of ideas on the choice of material, as well as the choice of the position and typology of assemblies, this was a crucial point for the dome project.

Convinced that cast iron was the most suitable material for curved trusses/vertical arches, Becquey explained in his report that they must be made in four sections – taking into account the maximum size of foundry moulds and ease of transport – thus reducing the length of each section to less than 20 feet (6.5 m). Based on the recent model of Austerlitz Bridge elements fulfilling the same function, the different sections of the arches would be assembled by means of tenons and mortises located at their ends, as well as struts with double projecting flanges on either side, "but these struts would be made of wrought iron rather than molten iron because of the excessive number of models required by their variety due to the unequal division of the base by the vertical arches".

In addition to the system of horizontal struts, which were eventually spaced only 7 feet (2.27 m) apart, Becquey observed that it would be advisable to consolidate the assemblies of vertical arches by means of wrought-iron beds or frames applied across the width of the arches or, alternatively, to extend the salient branches of these struts so that they might also serve as beds. The second solution was eventually adopted.

The superiority of cast iron for large parts that have to be manufactured in vast numbers, therefore, seemed to be a given. The cost of preliminary model manufacture was, indeed, amortized by the series effect (repetitive elements); however, in the case of wrought iron, the size of the elements would have required a significant mobilization of specialised labour, without assurance of a satisfactory result: "There is no doubt that the two members cast together will be more solidly linked than wrought-iron members joined together by dovetail keys embedded in a welded mass the adhesion of which is rarely perfect, even in less massive and more manageable ironwork".

In the conclusion of his report, Becquey reviewed and fully shared the five points in favour of an iron construction already mentioned in Bélanger's brief; here are the first two of these points: "1 – That this kind of construction has the advantage of not generating thrust, and can be used on existing constructions without drawbacks; 2 – That its total weight of 1,180,000 pounds spread over the 25 pillars will not exceed 47,200 pounds on the weakest of them, thus presenting absolutely no concern about the effects of such a modest overload on the pillars".

Having made his case, Becquey gave his final opinion: "The undersigned believes that a dome composed of vertical arches of molten iron linked by wrought-iron struts and seated on a base solidly resting on the existing pillars could meet the government's expectations. … Paris, 31 July 1807".

2.2 *Notes by Crétet*

After receiving the report, the members of the Special Commission expressed themselves on 20 August 1807 in favour of a metallic structure; they took this opportunity to provide information about the deterioration suffered by the vaults of the porticoes and attics of the hall. The report and the opinion of the commission were sent to the Ministry of the Interior. Only three days later, Emmanuel Crétet, who had just been appointed Minister of the Interior, sent Bélanger and the members of the commission a note containing his observations on the report in question and the technical solutions it outlined. Though not trained as an engineer, the new Minister had already demonstrated a predisposition for technical and managerial aspects during his previous political career. Around 1801–03, he had actually been called upon as State Councillor to head the Department of Ponts et Chaussées. In this role, among other things, he had been in charge of the works of the Pont des Arts and the Pont d'Austerlitz.

Given the need to build new structures to ensure a proper base for a stone dome, Crétet had to reject this option and support the choice of an iron dome. He also considered that the Becquey report amendments to the Bélanger scheme could be the basis for a sound project. Emphasising the opportunity to consolidate the small vaults of the building by filling them, he gave an apparently insignificant indication which ultimately lead to the construction of a dome made of a single material, i.e. cast iron, for both trusses and struts: "I believe one should fill in the small vaults, which are not very solid; this done and with a circular platform of molten iron embedded in the stone base, equal spacing between the vertical arches will no longer be inconvenient, an important condition for a construction that remains visible" (Crétet 1807). In spite of the conciseness of this statement, Crétet addresses here the essential point of the spacing of the large curved trusses, which can only be perfectly regular, especially for a completely visible structure. This fundamental condition, which is a matter of respecting the fundamental principles of architectural composition, was no longer questioned.

The presence of a circular base, consisting of a cast-iron platform embedded in the stone, indeed allows the weight of the dome to be evenly distributed over the pillars of the inner wall. The possible alignment of the axis of the trusses with that of the pillars, therefore, becomes unnecessary, and the absence of unequal division of the base brings us back to the idea of a dome entirely made of cast iron. Indeed, regularly spaced trusses having identical struts for each horizontal row, minimises the number of models and foundry moulds required. (Each horizontal circle consists of 51 identical elements). Crétet takes up the case again a little later: "I would add that, assuming equally spaced vertical arches, the system of molten-iron struts could be usefully employed. It would be appropriate to use only one kind of metal to avoid different expansion results. I don't think that a significant economy can be made by using cast iron struts, but this would bring more unity to the system and only a small number of simple models would be needed to make them".

Though only briefly, the second subject addressed by Crétet was the number of voussoirs that made up the trusses. Without really going into details on the aspects concerning the position or the typology of the assemblies, he simply noted: "I believe that the arches should be cast into three pieces and joined together by molten-iron muffles, in which the arches would be welded with lead".

Crétet, who had only recently taken up his post, was also working on the issue of repairs to the Austerlitz Bridge (Gauthey 1809) and on launching the construction of the new Iéna Bridge (previously called the Champ de Mars Bridge) which was meant to be built in cast iron like the Austerlitz Bridge. (This was modified by an imperial decree of 1808 ordering that the bridge be built in stone). Though it is not known whether the indications contained in Crétet's note corresponded to solutions autonomously conceived by the Minister or resulted from exchanges with engineers around him or people in charge of these various works, this document served to encourage further thinking about technical solutions and to the reaching of the final version of Bélanger's project. In fact, the instructions given in Crétet's note were perfectly clear: "This note will be communicated to the Commission, inviting it to make its final observations, based on which the construction project will be decided upon".

2.3 *Observations of the commission*

The commission only took a few days to send its comments to the Minister in response to the note of 23 August. Although, as the title shows, Bélanger was the official addressee of the note, the Minister seemed to consider the commission members as his privileged interlocutors. Moreover, Bélanger chose to remain in the background, and when he later evoked his responses to the Minister's notes, he simply repeated the arguments already formulated by the commission. In response to the Minister's notes, the commission's observations were organised around six points. The second, third and last of these points are discussed below.

The second observation dealt with the characteristics of the cast-iron platform embedded in the pedestal forming the base of the dome. Crétet asked that this circular element be designed to allow perfectly regular spacing of the vertical arches, an essential condition for a construction that was to remain visible. Strangely enough, this point is what made the members of the commission remain hesitant. Their remarks focused on two different aspects.

On the one hand, the existence of a continuous platform had the disadvantage of making the pedestal participate in the movements resulting from the positive or negative thermal dilation that a metal structure undergoes alternately when exposed to the heat of summer and the cold of winter. This would be relayed to the vaults of the attic and, more generally, to the pillars and the lower walls. According to the commission, the platform had to be made of separate pads joining only the two trusses corresponding to one and the same pillar. On the other hand, while admitting that equal spacing of the vertical arches would certainly be preferable, the commission members explained that since this condition seemed impossible to meet, given the irregularity of the lower arcades, the arrangement of the trusses should rather depend on having two trusses correspond to each pillar, in a symmetrical fashion with respect to the axis of the pillar; this would make the unevenness of the spacing between trusses almost negligible.

It is clear that almost everything was being done by the commission members to safeguard the hall and protect the masonry structures from the harmful effects of the weight or any movement of the new dome. However, these arguments were put forward to the detriment of another crucial aspect: only the presence of a continuous circular platform is, indeed, able to relieve the arcades and vaults of the hall from the horizontal thrust relayed by the dome from the impost to the lower structures. Moreover, retaining a regular spacing of the vertical arches and, thus, accepting the imperfect alignment of trusses and pillars (with minimal eccentricities) immediately leads, as we have seen, to having struts of identical length within one horizontal row. The commission addressed the subject, once again, in its last observation.

In response to Crétet's suggestion that the vertical arches be made up of three voussoirs joined by cast-iron muffles in which the arches would be welded with lead, the commission members first remind us, in their third observation, that Bélanger had proposed casting the vertical arches into five pieces which had been reduced to four.

It is easy to understand that the number of voussoirs which make up a truss is dictated by two partly contradictory criteria. Indeed, this choice results, at least initially, from structural cost and feasibility considerations. As the number of parts increases, they will be shorter and lighter, but each truss will have more bolted joint connections and, thus, more junction girdles. If, on the other hand, longer parts are used, less parts and connections will be needed, but their size and weight may cause problems during casting, transportation, lifting and assembly.

Regarding connections, i.e. the joining of the parts forming the vertical arches, the commission clearly favoured solutions other than the one suggested by the Minister. Possible lateral forces that could generate torsional effects would, indeed, be better absorbed by wrought iron frames or by struts with branches that would be extended and braced by buttresses. As we have seen above, the solution adopted was derived from the latter approach, where the extended branches of the junction struts cover the joints of the vertical arches.

Towards the end of the document, Crétet's stance on the spacing of vertical arches was addressed, once again, in relation to the choice of material. It is, in fact, by assuming regularly spacing of the vertical arches that one can consider using struts in cast iron rather than wrought iron. In their last observation, the commission members thus returned to the reasons for not maintaining equal spacing of the vertical arches; they also argued that this arrangement would lead to adopting a system of cast-iron struts probably preferable because more economical, since equal spacing on the same horizontal row of struts would considerably limit the number of models. However, according to a largely debatable view, the commission considered that these struts would not connect all the elements of the dome as accurately and precisely as would wrought-iron struts, which were more likely to fit any local situations or imperfections.

Without being adamant about it, the commission nevertheless seems to have finally opted for a solution involving vertical cast-iron arches and wrought-iron struts – the one Becquey de Beaupré had suggested in his first report. The commission's conclusion moreover promoted wrought iron for its mechanical characteristics and its behaviour under temperature variations: "In the event of a torsional movement or even a tendency to such a movement, the wrought iron struts will resist more effectively, and if in the opinion of His Excellency there should be no great economy in the use of molten iron struts, the principles of solidity and stability should make wrought iron the preferred option for the system. As for the difference in dilation of the two materials, it should be considered favourable to the system of wrought iron struts, which is more ductile and therefore more amenable to changes in shape caused by temperature variations – while this cannot be expected of molten iron struts" (*Observations …* 1807).

3 NOTES ON THE SIZING OF THE ELEMENTS

In a slightly later phase, better documented through plans and drawings than written documents, Bélanger submitted his studies, some of them in the form of models or prototypes, for validation by certain commission members, which no doubt included Becquey and Gaspard Monge (who chaired the Special Commission). This exploratory process made it possible to finalise the construction drawings of the cast-iron or wrought-iron elements and the drawings of all the assemblies. was concluded fairly quickly once the commission members had made univocal and definitive choices regarding the layout of the base platform and the number and length of the voussoirs of each truss, which required determining the number and position of the connections and junction girdles. It was also necessary to establish the thickness of the various elements, which, as we saw earlier, determined their strength. Only one point remained to be decided: the use of wrought iron in certain parts of a structure that was not yet expected to be mainly made of cast iron, though that turned out to be the final version (Figure 3).

Towards the end of 1807, or at the beginning of 1808, shortly after the exchange between the Minister of the Interior and the commission members, the dome became an object entirely made of cast iron. Indeed, from a certain point onwards and without it being known which scholar or administrator directed this choice, the commission engineers seemed to agree on the fact that a continuous circular base platform could distribute the relatively low weight of an iron structure uniformly on the pedestal and on the arcades; this meant that there would be no influence on load descent from the dome due to eccentricities between the axis of the trusses and the axis of the arcades or the lower pillars (which would be visible if regular spacing was maintained between trusses). At this point, one could consider a perfectly regular grid, where the struts were identical elements along the same girdle, which could

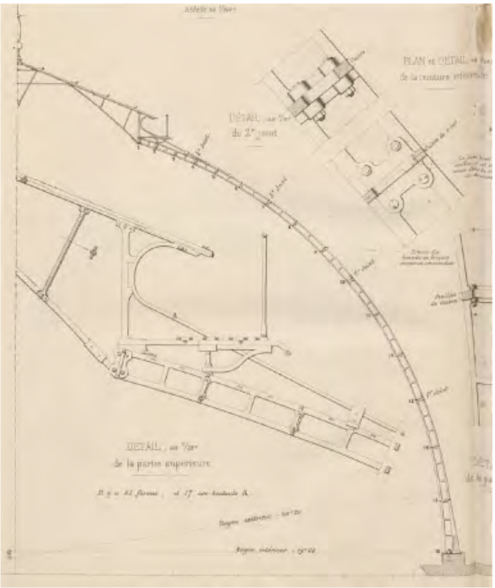

Figure 3. The final version of the framework – trusses composed of five parts. The drawing also shows details of the connection between two voussoirs and the struts of a junction girdle, and the attaching zone between the trusses and the skylight. Le Génie civil, 8, XIII, n. 16, 18/8/1888, pl. XVII.

be easily and economically manufactured in cast iron using a limited number of models. The apparent caissons could thus be considered as compartments inside which was inscribed a circle with two adjacent arches and two parallel struts as tangents. As for the number of voussoirs making up each truss, this decision could only be taken on the basis of the specific constraints of melting and moulding operations communicated by the representatives of the Le Creusot foundries, particularly for the length of voussoirs. On the other hand, the subdivision of the trusses also determined the number and position of assemblies and junction girdles. We can assume that once the number of voussoirs had been determined based on moulding constraints, their respective lengths and, therefore, the exact position of the joints was partly influenced by Coulomb's theories on the stability of masonry arches, even though these could only be rigorously applied to arches and vaults.

The most significant contributions on structural science during the last quarter of the 18th century and before the publication of the Navier lessons were the ones concerning the equilibrium of masonry arches, elaborated by Charles-Augustin Coulomb and presented at the Royal Academy of Sciences in 1773 (Heyman 1997). In engineering circles at the turn of the century, the generally accepted interpretation concerning the instability of arches and vaults according to Coulomb's model therefore referred to the formation of hinges at certain joints between voussoirs prior to collapse.

In the case of the hall dome, the studies were most likely primarily concerned with the design of the curved trusses (vertical arches) as the main load-bearing element. In a preliminary phase, each curved truss could be seen as half of a semi-circular arch. The horizontal thrust of the arch at its imposts was entirely compensated here by the base girdle of the dome. In addition, the key of such an arch was absent or replaced by the girdle delimiting the central oculus on which the skylight rested.

Approaches to design an arch or a vaulted roof correctly resulted directly from Coulomb's solution to the problem concerning "the equilibrium of vaults, taking into account friction and cohesion" (Coulomb 1776): it was based on a mechanism resulting from a search for *maximis et minimis*, which highlighted the four different limit situations preceding rupture. In the case where the possibility of any voussoir slippage is excluded, the two remaining limit situations refer to the possibilities of rotation between voussoirs. This mode of failure is likely to lead to rupture of the arch into four parts by the formation of hinges. The key, which was absent from the curved trusses of the dome, did not have to be taken into account, and any rotation at the imposts was considered prevented by the embedding effect provided by the base girdle anchored in the hall wall. Therefore, in the specific case of the Bélanger curved trusses, there was only a risk of rupture linked to the joints possibly placed close to an angle of 30 degrees with respect to the axis of symmetry of the semi-circular arch. Indeed, in this position, the facets of the voussoirs revolve around the lower edges – points of the intrados. We shall see later that it is not unfounded to suppose that preliminary studies for the dome had precisely planned to avoid this type of joint in the subdivision of the trusses into voussoirs.

Finally, defining the thickness of the elements was actually a matter of determining the quantity of material required to obtain voussoirs that were sufficiently massive to resist the acting loads yet remain as light as possible. This question, which, as mentioned above, is the other major aspect of the truss project, had already been raised in the studies on cast iron bridges built with frames. The aim was to use model tests in order to compare the resistances provided by cut stone voussoirs and hollowed out cast iron frames of the same length and weight as those made of stone (Davy de Chavigné 1801).

3.1 *Further questions raised by the project*

As construction was about to begin and during the initial phases of the work, between the second half of 1808 and autumn of 1809, some uncertainty remained regarding the assembly or the subdivision of the trusses into frames (Figure 4). Corrections were made compared to the initial project plans and drawings published in 1808. Some of these concerned assembly details or the layout of the base circle, but the most significant decision, apparently taken between the end of the summer and early autumn 1809, concerned the subdivision of the trusses into frames as well as the nature of the material used for their manufacture.

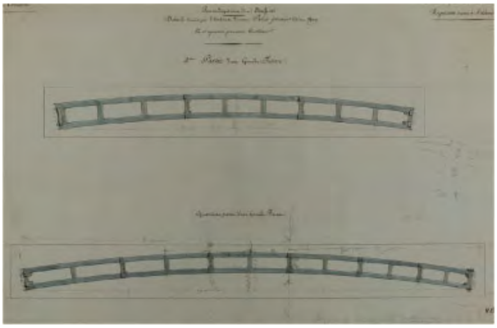

Figure 4. Subdivision of a curved truss into four parts – a solution not retained. Third and fourth voussoir, about 4.9 m and 6.2 m respectively, 1 August 1809. Hittorff coll., H.B. 165, Wallraf-Richartz Museum. Ph. D. Bongartz.

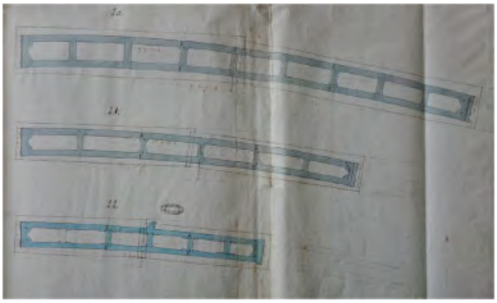

Figure 5. Subdivision of a truss into five parts – executed project. Third, fourth and fifth voussoir ≈4.9 m, 3.6 m, 2.6 m. Different colours indicate the materials used. The fifth wrought-iron voussoir is shown in light blue. Arch. nat., F/13/1164.

The first studies planned that the trusses should be made up of only four parts, joined together by the struts of three junction girdles and made entirely of cast iron. This version of the project seems to correspond to the one sent by Bélanger to the Special Commission and to the Minister of the Interior in 1807 and in 1808 (*Recueil* … 1808), as well as the one described by Brunet in his memorandum published in 1809.

In his initial scheme, Bélanger had considered melting the vertical arches as five pieces, reduced to four by Becquey and the commission. With this option, decided on early and validated several times, the fourth piece of the vertical arches, which was intended to receive the skylight structure, seemed to be much longer than the others, the length of which decreased gradually from the first piece, starting at the base, to the third. The last piece was then divided into two unequal frames, which increased the number of frames per truss from four to five while preserving decreasing lengths for all the frames, from the base frame to the one supporting the skylight. This was also an advantage when the parts were being lifted. At the same time, it was decided to make the fifth frame, the shortest and thinnest, out of wrought iron rather than cast iron (Figure 5). This unexpected change in material also applied to the last three girdles of the dome, including two uniting girdles and the last girdle on which the skylight rested. (Sampling and analyses carried out during the recent restoration of the dome confirmed the presence of these two materials.) The only, probably partial, explanation we have been able to identify for this change in material is linked to the reduced thickness considered for these parts, which were also the shortest and, therefore, became amenable to forging under economically favourable conditions; we do not know whether other reasons contributed to this choice.

One might put forward arguments that could explain the configuration of the first study with a truss divided into four voussoirs, including a fourth long voussoir made of cast iron, and might shed light on what probably prompted the use of a fifth short voussoir made of wrought iron. However, it is objectively difficult to provide convincing and definitive answers on all these points.

The first solution with a fourth long segment could be explained by the attempt to remedy the supposed risk of dome rupture at the joints placed close to an angle of 30 degrees with respect to its axis of symmetry (Coulomb model). Avoiding any interruption of the curved trusses at this location would have protected the dome from the risk of collapse by the overturning of the voussoirs around the lower edges of these joints, even though Coulomb's methods applied more to vaulted roofs than to domes.

The final design, which cannot be considered a fall-back solution, ignored this type of risk and abandoned the previous considerations, making it possible to create a succession of five voussoirs of gradually decreasing size and weight and, thus installed an end voussoir in direct contact with the skylight. Placed on the dome, this element made of wrought iron and fitted with glazing, was particularly exposed to the action of the wind due to its elaborate shape which included a service floor with a balustrade and a lightning rod. It was, therefore, likely to relay to the upper part of the trusses bending forces that would have been to some extent detrimental to cast-iron voussoirs. On the other hand, the choice to make a fifth voussoir, as well as the struts of the last three girdles, out of a ductile material such as wrought iron gave the upper crown of the dome increased mechanical capacity, especially in terms of absorption of the bending or torsional stress that went from the skylight to the trusses. The regular morphology of the dome being interrupted by the skylight, it was, therefore, possible to consider the last voussoir and the last three girdles of the structure as forming a transition zone between the spherical surface of the dome and the skylight. These voussoirs and struts, made after the moulding of the cast-iron parts and provided shortly before or at the time of the late delivery of the skylight irons in December 1812, could also be perfectly adjusted on site to the final design of the skylight half-trusses.

The designing of the structure was, therefore, an exercise based on an empirical approach and influenced by studies carried out for the other major cast-iron structure during that time, namely the Austerlitz Bridge. In the preliminary design studies, the dome was most likely compared to a vaulted stone covering and designed, as far as the curved trusses and their voussoirs are concerned, on the basis of the methods developed by Coulomb, as well as recent construction examples, most notably Soufflot's and Rondelet's Panthéon.

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History of Construction Cultures – Mascarenhas-Mateus & Paula Pires (eds)

The development and use of non-staining cements in American masonry

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ABSTRACT: The history of masonry mortar binders in the United States is unique and complex. Among the less extensively studied materials are the non-staining cements used in conjunction with light-colored masonry materials. Within the American timeline, perhaps the most interesting period for these binders is the late 19th and early 20th century. During this period, there are clear regional trends in material usage based on availability. Slag cement mixes were employed in areas where steel manufacture was a prominent industry. Grappier cements were imported from France and limited mainly to regions near ports of entry on the East Coast. White Portland cements were not produced until the turn of the 20th century but became the dominant non-staining cement relatively quickly. In addition to patterns of use, it is important to understand the general properties of these mortars as these impact on the ongoing performance of the masonry.

1 INTRODUCTION

1.1 *Defining "non-staining" cement and "American" masonry*

The key topics of this discussion must be defined within the context of this paper. Herein, the term "non-staining cement" applies specifically to hydraulic binder materials with low iron contents that are intentionally used in setting and pointing mortars in light-colored masonry. Non-staining cements are employed in these applications for both aesthetic and performance-based reasons. In the United States, the late 19th and early 20th century saw advances in the development of these binders and their expanded use in masonry mortars adjacent to limestone, marble, granite, terra cotta, and glazed brick.

It should also be noted that the term "American" is used here to refer to products manufactured and/or employed in the United States of America. The author realizes that this definition of "American" is not inclusive of the broader, richer historical and cultural context of the entire North and South American continents. In fact, the materials and trends discussed in this paper likely also apply to eastern Canada in addition to the United States. Nonetheless, this phrasing has been chosen here simply for the sake of brevity and clarity, regardless of the shortcomings of its application.

1.2 *A brief introduction to binder usage in the United States*

Nonhydraulic common limes, have arguably been the most common non-staining binders used throughout construction history not only in the United States but also worldwide. Until the turn of the 19th century, virtually all mortars in the colonized United States were prepared using this binder. However, the advent of natural cements, first imported from Europe and then manufactured domestically, gave rise to a class of hydraulic binder materials, which set underwater. These cements set more rapidly and generally contribute to increased durability compared to common aerial limes. Roman cements from England were first imported around the turn of the 19th century. Beginning with the construction of Erie Canal ca. 1818, domestic natural cements were manufactured in the United States. The most widely manufactured and distributed of these American natural cements were those produced in the Rosendale district of New York. The production of these natural cements persisted through the mid-20th century and has more recently been revived, specifically for use as restoration binders in historical projects.

Though artificial Portland cements were first manufactured in England in the early 19th century, these were not imported into the United States until the 1860s. Domestically, David O. Saylor began making Portland cements in Coplay, PA in the 1870s. However, there was no large-scale manufacture of these American Portland cements until ca. 1883. (Mueller 1908)

For all their advantages, natural cements and (later) Portland cements contained iron-based phases that contributed to their brown and gray colors, respectively. The iron-bearing binders also have the potential to produce unsightly staining around the edges of light-colored masonry units (Chase 1906). This can result from small influxes of moisture that mobilize the iron phases in the mortar and either run from the joint faces or wick through permeable masonry units. Prior to the advent of non-staining cements, it was necessary to coat masonry beds and joints with waterproof paints or asphalt-based materials to prevent this kind of iron staining.

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The desire for hydraulic binders that were white in color and did not stain the adjacent masonry led to the domestic manufacture and importation of various kinds of non-staining binders. Trends in the employment of these materials varied regionally and were largely dependent upon availability and, in some cases, the politicization of commerce. It should be noted that this paper is not intended as an exhaustive history of these products but rather an introduction to the development and use of a class of binders that are not widely understood within the building preservation/conservation community.

2 SLAG CEMENTS

2.1 *Defining slag cement*

Slag cements are the earliest of the domestically produced non-staining cements to be employed in the United States and continue in use as masonry mortars to this day. However, these were not originally developed with this express aesthetic purpose in mind. In the historical literature, the term slag cement may be used to refer to a variety of binder materials. In the context of these non-staining cements, "slag cement" refers specifically to a mixture of slaked lime and ground granulated blast furnace slag. The hydraulic characteristics of this binder are due solely to the pozzolanic reaction between the glassy slag and the alkaline lime paste. No other hydraulic cement additions are present. The term "slag cements" also excludes any other historical lime-pozzolan mixes, such as those containing Italian pozzuolana or Dutch trass (or terass), which may have been more commonly employed in Europe. Presently "slag cements" are another term for ground granulated blast furnace slag itself employed as an addition to concrete and mortars.

2.2 *Development of slag cement*

The slag acts as an artificial pozzolan when mixed with lime. The calcium hydroxide in the lime paste dissolves the siliceous glass to generate the hydraulic product calcium silicate hydrate. The use of this kind of pozzolanic reaction in masonry materials dates back to the Romans employing a mixture of lime and actual pozzuolana, a volcanic ash, to make concrete. In European countries and their colonial territories, volcanic ashes such as Italian pozzuolana and Dutch trass continued to be used with lime to produce hydraulic masonry materials.

In as early as 1872, slag cements were being thought of specifically for non-staining purposes. An article in the American Artisan mentions treating slag using sulfuric acid to precipitate out iron in the form of iron sulfide (American Artisan 1872). However, this was not a universal process and the material was not marketed specifically as a non-staining cement until later in the 19th century.

Slag consists of the lighter elements that float on top of the molten mass of metal and are then removed from the steel as contaminants. Though the combination of slag and lime to make slag cements became more common in the late 19th century, the idea of using blacksmiths' slag in the place of imported Italian pozzuolana and mixing it with slaked lime was noted back in 1813 (Chaptal 1813). Of course, as slag is a byproduct of the steel manufacturing process, it was not widely available as an artificial pozzolan until the industrial revolution during the mid to late-19th century.

In order to produce ground granulated blast furnace slag, the molten slag is cooled and granulated by running it through a stream of cold water. The granulated slag is then ground and screened to produce a fine powder. In order to make a slag cement, the processed slag is then mixed with hydrated lime and the mixture is ground into a homogenized powder (American Architect and Building News 1888; Scientific American 1886; Spalding 1921; Taylor 1907).

Historical slag cements reportedly employed high-calcium, nonhydraulic fat limes (Eckel 1907; The National Builder 1897). The lime was typically slaked with just enough water to produce a fine, dry powder. This was the typical process in slag cement plants, using industrial hydrators even before dry hydrated lime was widely available in the pre-packaged form in the United States (ca. 1910) (Eckel 1905).

Early experiments were performed on slag cements in the 1860s and 1870s, comparing these to contemporary Portland cements. These experimental slag cements reportedly contained the equivalent of 14 to 20 parts lime for every 100 parts of slag by weight (Bodmer 1873; Nursey 1875). By the time these products became more widely used, however, slag cements typically employed a higher proportion of lime. Early 20th century products typically contained between 20 and 40 parts lime for every 100 parts of slag by weight (Eckel 1905; 1907).

2.3 *Performance of slag cements*

Slag cement mortars can exhibit a range of physical properties, depending on the reactivity of the slag itself as well as the environmental conditions to which the mortar is exposed. These features can affect both the strength and permeability of the mortar, which in turn often correlate with the durability of the joint.

The reactivity of the slag itself is dependent upon both its chemical composition and how finely it is ground. The former is not controlled by the manufacturer. However, slag reactivity can be tested before using the material for cementing purposes. For example, an 1872 article in the American Artisan mentions mixing slag with muriatic acid in order see if a "jelly-like mass" is formed. This would indicate the production of amorphous silica from the slag reaction (American Artisan 1872). Historically, slags with higher alumina (Al_2O_3) contents were noted as yielding stronger cements (American Gas Light

Journal 1880). However, mortars containing excessively aluminous slags reportedly tended to crack. Scholars of the day noted that slags used in slag cements ideally have an Al_2O_3/SiO_2 ratio of between 0.45 and 0.5 and that slags with higher free lime (CaO) contents are generally more reactive (Eckel 1928; Taylor 1907).

The grind of the slag can also contribute to its reactivity. In a more finely ground slag, there is a greater surface area of siliceous glass available for pozzolanic reaction with the alkaline lime paste. Though many slag cements are ground after mixing, much of the size reduction occurs upon granulating the slag. Early 20th century experiments demonstrated the development of higher tensile and compressive strengths in mortars using granulated versus ungranulated slag (Mills 1915). The author's laboratory has also observed slag cement mixes in which the slag is coarsely ground and the resulting mortars have undergone only very limited pozzolanic reaction. As a result, the slag grains act essentially as inert aggregate particles, and the observed mortar performance is similar to that expected for nonhydraulic, common lime mortars with higher-than-intended sand contents.

In addition to the reactivity of the slag itself, the physical properties of the slag cement depend on the alkalinity of the lime paste. Upon carbonation due to exposure to air, the pH of the binder paste is lowered and the pozzolanic reaction is inhibited. This also appears to have historically been part of the industry knowledge. A 1912 treatise on cements notes that a slag cement "should *never* be used where it may be exposed to the action of dry air for long periods". The same treatise notes that slag cements can have variable compositions and uncertain properties (Cochran 1912).

This variability in the performance of slag cements is reflected in the historical literature, where various experiments yielded differing interpretations with regard to properties such as set times and strengths. For example, an 1888 article equates the set time of slag cement to that of American Rosendale natural cement rather than Portland cement, noting that slag cements generally set in 2–8 hours rather than half an hour (American Architect and Building News 1888). Another 1897 article notes that, in many cases (but not all) slag cements set somewhat more slowly than Portland cements (The National Builder 1897). In contrast, a 1904 specification states that slag cements should not be used because a slow-setting cement will be required (Navy Department 1904).

Some historical literature makes comparisons of strength between slag cements and Portland cements. However, it can be argued that these shorter term evaluations do not take into account the potential long-term pozzolanic reactions that may continue to produce hydraulic product as long as the mortars remain alkaline and uncarbonated. Of course, the long-term strengths of these mixes are rather unpredictable as these depend upon the exposure of the mortar and the ability for the reaction to continue.

Based on examined historical mortars containing slag cement binders, the author has observed a wide range of physical properties. These have varied from mortars that are soft, punky, and permeable with characteristics closer to those of common lime mixes than to mortars that are hard, indurate, and impermeable as may be achieved from pure Portland cement mortars.

Though slag cement mixes cannot be identified from visual analysis alone, one interesting feature is the presence of a bluish-green color in uncarbonated areas of the paste. This is also noted historically and described as fading upon exposure to air (Taylor 1907). This color is attributed to calcium sulfide in the binder that reacts upon carbonation. Despite this coloration, slag cements were noted as being among the lightest in color of the non-staining cements available around the turn of 20th century (Sweet's Indexed Catalogue 1906).

2.4 *Trends in use of slag cements*

Despite experiments with these products earlier in the 19th century, slag cements were not widely manufactured or employed as non-staining cements in the United States until ca. 1890. Slag cements are most often found in historical mortars used in regions with steel manufacturing centers. This is reasonable since the slag would have been derived from steel production and plants for slag cement manufacture were generally located within these centers.

Among these industrial centers was Birmingham, in the southern state of Alabama. In the Birmingham region, the Southern Cement Company was established ca. 1895 and produced the Magnolia Stainless Slag Cement. Later, the Cheney Lime and Cement Company began manufacturing their Vesuvius Slag Cement in 1929 (Burchard 1940).

Chicago represented another steel production center, and the Illinois Steel Company was also manufacturing "Steel Portland" cement, a slag cement, around the turn of the 20th century. At the same point in time, other slag cement factories were reportedly in operation in Ohio, New Jersey, and Pennsylvania. (Eckel 1905) There are reports of a slag cement plant at Sparrows Point in Maryland around the turn of the 20th century although the plant was no longer in operation by 1910 (Mathews 1910). By 1912, a plant in Buffalo, NY is also reported to have manufactured slag cements (Flat Roof Construction 1913).

In addition to these domestic products, some slag cements were also imported from Europe. The most widely publicized of these appears to have been the Meier's brand, imported from Germany and sold out of Louisville, KY throughout the 1890s and the early 20th century. In fact, this product was marketed as having been employed in nearly all federal government buildings over the twenty year period from ca. 1890–1910 (Boston Architectural Club Yearbook 1910; Hendrick's Commercial Register 1891).

3 GRAPPIER CEMENTS

3.1 *Development of grappier cement*

Grappier cement was an imported non-staining cement product manufactured by the Lafarge Cement Company in France. Historically, this may have been referred to as an imported "non-staining Portland cement" in the late 19th and early 20th century. Though this comparison may have been a fair comparison in terms of performance, grappier cements were produced from completely different processes and source materials than those used for Portland cements.

Prior to the development of grappier cement, the Lafarge company manufactured hydraulic lime from a white, argillaceous limestone at Teil in France. The manufacture of this natural hydraulic lime (NHL) began in the 1830s and persists to this day. There is some mention of imports of these Lafarge products from Teil in as early as 1865. (New York Times, 1935) However, NHLs were not regularly imported into the United States until fairly recently, in the late 20th century, and even now mostly for usage as a restoration binder in historical buildings.

Grappier cement was a shorter-lived product, particularly as regards its utilisation in the United States. According to historical articles and patents, grappier cements were produced from the 1880s until at least the late 1960s. (Bertozzi, 1972; Hodgson, 1882) However, their use in American masonry mortars was more limited to the late 19th and early 20th century almost exclusively for their non-staining properties. By the late 1930s, imported grappiers were essentially driven out of the market by domestic white Portland cements.

3.2 *Process of manufacture*

Grappier cement is a hydraulic cement made from the unslaked material left behind from the manufacture of hydraulic lime. The "grappier" are lumps of underburned and overburned limestone that remain when hydraulic lime is slaked. The overburned grappier contain silicates of calcium and aluminum formed at higher temperatures. The grappier are then ground and sieved. Then, the ground material is exposed to air in order to allow for the air-slaking of any remaining free lime so that there is not any unslaked calcium oxide present in the grappier cement product (Spalding 1898).

The crystalline silicate phases in these grappier cements have not been extensively studied. However, petrographic examinations performed at the author's laboratory suggest these include some higher-temperature calcium aluminosilicate phases. These clearly distinguish the grappier cements from white Portland cements microscopically as the major constituents of the latter include only belite, alite, and tricalcium aluminate. These binders are also distinguished chemically by the higher content of silica in grappier cements than in white Portland cements.

3.3 *Performance of grappier cement*

Since grappier cements are no longer produced, we must rely to some extent on the historical literature to understand their physical properties. However, studying existing grappier cement mortars may also serve as a benchmark for understanding performance. It could be argued that there was some potential for variable quality in these cements since they are manufactured from byproducts of another material process. However, historical accounts suggest that the product was relatively well quality-controlled by the Lafarge company (Eckel 1907).

Compared to Portland cement, grappier cement was described as a superior, less expensive product and sold as a slow-setting cement (Spalding 1898). A ca. 1921 experiment comparing the tensile strength of grappier cement mortar to French Portland cement mortar shows that, within about three months, the grappier cement mortar developed roughly equivalent, slightly higher, tensile strengths than its Portland cement-based counterpart (Eckel 1928). It should be noted that the historical gray Portland cements against which these were originally compared were manufactured at lower temperatures and less finely ground than modern Portland cements. Though the grappier cements exhibited slightly higher tensile strengths than their early 20th century Portland cement counterparts, modern Portlands may be expected to be more rigid and impermeable than either historical product.

Nevertheless, based on qualitative assessments of historical mortars with grappier cement binders, the service performance of these mixes appears to be relatively similar to that of Portland cement-based materials. These binders tend to produce mortars of relatively high strength that are rather hard and brittle.

3.4 *Trends in use and importation of grappier cement*

The author's laboratory has observed trends in the use of this material by age and location based on years of investigative mortar analysis. It is clear that grappier cements were mostly employed in the Northeastern United States near cities such as New York, Boston, and Buffalo. This binder has been found almost exclusively in light-colored masonry from the late 19th and early 20th centuries. The laboratory has also observed grappier cement mortars employed in this context in Canada. However, a larger discussion of the use of grappier cements outside of the United States is beyond the scope of this particular paper. It is possible that these grappier cements may have been adopted to a greater extent in the United States than in Europe due to the large, exposed surfaces of high-rise structures in the United States that needed "secure, even color". The non-staining qualities of this product were perhaps less highly regarded in Europe, where buildings remained on a smaller scale through the beginning of the 20th century (The Construction News 1906).

Despite its touted performance and lower cost of manufacture, grappier cement was no match for domestically-produced white Portland cements in the long run. The Portland cement industry lobbied to impose tariffs on imported non-staining cements, raising their price by 10% by 1913 while other hydraulic cements were duty-free (Comparison of tariff acts, 1915). In addition to any import tariffs, the American railroads themselves reportedly designed their rates to hinder the transportation of these foreign cements by rail (New York Times 1930). As such, it is not surprising that grappier cements were mostly employed in cities along the eastern seaboard.

American Portland cement manufacturers also marketed their white cements as superior and home-grown while painting the use of these foreign imports as unpatriotic. By the 1930s, multiple newspaper articles called for the cancellation of orders of imported non-staining cements for government-funded projects even in these eastern cities (New York Times 1935).

It should be noted that this discussion of grappier cement and its use in the United States is limited to an examination of the historical literature (in which it is not consistently named) and to its first hand identification within mortars analyzed solely by the author's laboratory. As more samples are tested, the understanding of when and where grappier cements were employed is expected to develop further. Some grappier cement-based mortars have likely been lost to repair over the years. Where these materials have been present, it is highly possible that they may have been misidentified as white Portland cements if at all ever subjected to analytical testing.

4 WHITE PORTLAND CEMENT

4.1 *Definition of white Portland cement*

Portland cement is an artificial cement manufactured by burning limestone, clay, shale, and/or other natural additives together to produce a desired composition. Since their inception, Portland cements have had a gray color due to their use of iron-bearing clays that produce a ferrite phase in the cement clinker. However, steps were taken at the turn of the 20th century to produce separate white Portland cements with lower iron contents to be used in non-staining applications. These are the most common non-staining cements used in American masonry mortars today and have arguably been so ever since the 1920s.

4.2 *Development of white Portland cement*

The rise of the Portland cement industry in the United States was quite rapid. Domestic Portland cements were first manufactured in ca. 1880 and became the most commonly used hydraulic cement within a couple of decades, outgrowing the American natural cement industry that had dominated much of the 19th century.

By the turn of the 20th century, there was a race to develop non-staining white Portland cements. The product appears to have been experimented with in as early as ca. 1900, and within the next decade white cements were being sold by multiple companies.

Among the key players in the development of American white Portland cements is Joseph Maxwell Carrère, an 1883 graduate of Columbia College. He is noted as having worked for the Atlas Portland Cement Co. from 1899–1903 before becoming the general manager at the newly established Blanc Stainless Cement Co. in 1905 (Jackson & Peele 1911). Although the Blanc white Portland cement is not commercially listed as a product in the industry literature until 1905, Carrère reportedly developed this product (or at least some version of it) in 1900 (Brown 1905; Mueller 1906).

A 1906 article by Mueller describes the development of Blanc cement as the "birth of a formidable rival" to foreign non-staining cements, specifically French grappier cements (Mueller 1906). The strategy of Mr. Carrère was to use Blanc cement in a small number of prestigious buildings to prove its worth rather than to attempt a larger scale marketing endeavor for its use in many smaller structures.

It cannot be overlooked that many of the buildings in which Blanc cement was first employed were designed by Carrère and Hastings, the highly respected architecture firm co-founded by Joseph Carrère's brother, John Merven Carrère. Among these structures are the Cathedral of St. John the Divine, the New York Public Library, and the New Theatre in New York City; the Carnegie Institution and the House Office Buildings in Washington, D.C.; and the Bi-Centennial Buildings at Yale University in New Haven, CT (Mueller 1906). Carrère and Hastings even designed the Blanc Stainless Cement Co. booth at the 1908 convention for the National Association of Cement Users, the precursor to the American Concrete Institute (Cement Age 1908).

Although the material had reportedly been in use since ca. 1900, Carrère does not claim to have perfected the cement until 1907. The Blanc Stainless Cement Co. filed patents in 1908 and 1910 outlining the process of manufacture. The process was reportedly the same as that needed to make ordinary Portland cement at the time with the exception that all the constituents be free from iron and other impurities. Specifically, the patents prescribed mixing roughly 75% calcium carbonate from a pure limestone and roughly 20% silica in the form of either pure silica or a white clay/shale. The remaining 5% consisted of a zinc carbonate flux to reduce the amount of heat necessary to clinker the cement (Carrère 1910).

Though the Blanc Stainless Cement may have been the first white Portland cement employed in actual buildings, another product was patented earlier by Spencer B. Newberry of the Sandusky Portland Cement Co. in Sandusky, Ohio. In this patent, Newberry proposed using a combination of pure limestone and siliceous clay as well as a cryolite flux. He also noted that the clay used should contain 2.5 to 3.5 times as much silica as alumina, and that ordinary white clays or kaolins do not meet this requirement (Newberry 1908).

Although Newberry filed this patent in 1905, the Medusa White Portland Cement from Sandusky was not officially patented and marketed until ca. 1908. The Sandusky Portland Cement Co. claims that the Medusa cement was the “first true white Portland cement” ever manufactured passing American Society for Testing Materials (ASTM) and United States government requirements. This appears to be true since its patent was approved prior to that for the Blanc Stainless Cement Co. (Sandusky Cement Co 1928).

In addition to the Medusa and Blanc cements, the Berkshire White or “Snow White” brand sold through the Vulcanite Portland Cement Co. was also listed as a white Portland cement manufactured in as early as 1908 (Cement Age 1908). Atlas White cement soon followed and was first produced in 1910 under the supervision of Hicks and Heyman at the Atlas Portland Cement Co. (Hadley 1945).

The rise of white Portland cement was swift. By 1913, it reportedly made up the majority of non-staining cements manufactured in the United States (Department of Commerce 1913). Although these may have overall become the leading domestic non-staining cements, slag cements were still commonly used in steel manufacturing centers. Foreign imports also continued to compete with white Portland cements for the next decade or so. These imports consisted mostly of grappier cements, employed predominantly in the northeastern United States. Alhough white Portland cements were also being produced in the UK and Germany, these did not account for any significant proportion of the non-staining cement imports (Brown 1905; Bureau of Manufacturers 1911).

In the 1920s and 1930s, some manufacturers began selling waterproof white Portland cements. Though waterproofing agents had been sold as separate additives earlier in the 20th century, these began to be incorporated into pre-packaged mixes. Waterproofing white cements were marketed for stucco work and pool linings in addition to any stone setting or pointing. The Sandusky Cement Co. claims their Medusa Waterproofing White Portland Cement was the first product of its kind. In this product, the waterproofing was integrally added to the cement and ground together with the clinker. This allowed the customer to purchase a pre-mixed waterproof binder rather than having to mix a separate waterproofing compound into the mortar on site. This minimizes any additional costs or concerns about adequate incorporation of a waterproofing powder or paste (City of Detroit 1937; Sandusky Cement Co 1928).

4.3 *Performance of white Portland cement*

Compared to the other non-staining cements discussed here, white Portlands were marketed as having superior strength and hardness (Sandusky Cement Co 1928). However, this may have stretched the truth ever so slightly as a matter of convenience and promotion. The properties of grappier cements were likely quite similar to that of white Portlands. Some slag cements, though their hardened properties may have been less predictable, certainly could have reached or exceeded the strengths of white Portland cements if the pozzolanic reaction continued over the course of service. Regardless, it certainly could be argued that white Portland cements were a more consistent product than the slag cements.

It may be speculated that white Portland cements exceeded their gray counterparts in strength during the first part of the 20th century. Since their inception, white Portland cements were typically fluxed in a different manner, producing a higher content of alite than in gray cements. The grind of the white variety was also consistently fine, while the gray cements were more coarsely ground in the early 20th century. Both the abundance of alite and the finer grind would have contributed to a higher strength product than contemporary gray Portland cements. However, by the 1950s, the properties of both materials were likely quite similar and in the same range as expected for the products manufactured today.

4.4 *Success of white Portland cement*

Of the non-staining cements discussed, white Portlands are certainly the most well-known and persistent of these historical binders. The success of white Portland cement as the dominant non-staining cement in the United States from the 1920s onward may be attributed to several factors.

First, its consistent quality and performance as a manufactured product cannot be discounted. Portland cements were well known and became the dominant cements used for a variety of mixtures in 20th century American construction.

Second, it was a domestically developed and produced material with a rapidly increasing number of manufacturers in the early 20th century. Many of these producers were already well-established companies within the cement industry, well equipped, and well positioned along railroad lines allowing for easy distribution of these products throughout the country (Brown 1906).

Finally, the national cement industry organizations banded together to distribute and market these products while lobbying to shut out foreign competitors.

5 MASONRY MORTAR APPLICATIONS OF NON-STAINING CEMENTS

5.1 *Typical mix design trends*

The following interpretations are based on the numerous historical mortar samples analyzed by the author’s laboratory firm, which specializes in the testing of historical American masonry materials. When building with non-staining cement mortars, it was common practice to prepare different bedding and pointing mixes in order to balance economy and performance.

These trends apply across the range of non-staining cements discussed in this paper, inclusive of the slag, grappier, and white Portland cements.

In addition to any of the non-staining cements, both the bedding and the pointing mortars may have included a nonhydraulic lime and a light-colored, iron-free sand (e.g., a pure, clean quartz sand or a crushed marble sand). The pointing mortars were typically stronger, denser, and more water-resistant. This would have been achieved with a relatively higher proportion of the non-staining cement in the pointing. The bedding mixtures in the same joints were often more economical mixes, diluted with additional lime. In some cases, the pointing mortars may also have employed lower sand contents.

As mentioned above, non-staining cement mortars would have typically been reserved for light-colored masonry such as marble, limestone, granite, and terra cotta. However, where these light-colored units are present as ornament or accent on building facades, the author has sometimes found more economical versions of these mixes in other parts of the masonry where non-staining cements would not normally be deemed necessary (e.g., common red brick). It might be speculated that these non-staining binders were used as a matter of convenience, already having the product available on site for the light-colored accents.

5.2 *Identifying the various non-staining cements in historical mortars*

It should be noted that these non-staining cements have been referred to by many different names historically. Care should be taken when examining the historical literature and job specifications. It is not uncommon to encounter recipes from the late 19th century calling for "white cement" or "non-staining Portland cement" though the time period clearly predates the advent of white Portland cements. Instead, this phrasing may refer to a slag cement or grappier cement. A grappier cement might have also, more specifically, been referred to as "Lafarge Portland cement" (Hodgson 1882).

As with all historical mortars, laboratory analysis is necessary to clearly identify and quantify the constituents of these non-staining cement mixtures. In advance of the laboratory testing, special care should be also taken when sampling these mortars since differences in mix design between beddings and pointings may not be as visually apparent as with mortars containing other types of binders.

The author advocates for these materials to be tested by a laboratory with expertise in historical mortar analysis. A combination of microscopical and chemical techniques, sometimes with supplemental instrumental analyses, is necessary to identify the distinct mineral constituents and measure the binder chemistry. The author's laboratory tailors their methods of analysis to each individual historical mixture in order to isolate and quantify the various components and estimate the original mix design. It is only through this advanced testing that the firm has been able to observe first-hand these trends in usage of these non-staining cement mortars.

5.3 *Implications for performance and repair*

It should be noted that the analysis and identification of these historical mortars is not only necessary for documentation purposes. It is also essential in providing specifiers with information to assist in understanding mortar performance and subsequent decisions regarding suitable repairs. Among the features to consider especially for these historical non-staining cement mixtures are the following:

Slag cements are known to produce mortars with varying properties depending upon the quality of the slag and the environment of the mortar joint. For these specific mixes, although determining a mix design may provide information for the historical record, it may be more prudent to understand the qualitative properties and condition of the existing mortar joint and masonry system in order to better identify a potential range of repair mixes.

Grappier cements are no longer produced. Although the author does not advocate for "replication-in-kind", this would not be possible for grappier cement mixes even if desired. The hardened properties of these mortars are in the range of those expected for mortars containing roughly comparable amounts of Portland cement. However, it is again important to consider the performance of the existing mortar and its exposure when designing repairs.

For white Portland cement mortars, specifying appropriate repairs may seem more straightforward given the consistency and continued availability of this product. Still, it should be remembered that other components of the mix can also contribute to performance. These include the amount of added plasticizer, the characteristics of the aggregate (including size, shape, and gradation), the original mix water content, and other placement features (such as degree of consolidation).

Regardless of the plethora of considerations that must be taken into account when designing mortar repairs, the author argues that understanding the binder and its properties is among the chief concerns. Not only does this allow for a greater understanding of the material within its historical context, but it also provides for some assessment of the current performance of the masonry and any potential changes in expected performance with the planned repairs.

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History of Construction Cultures – Mascarenhas-Mateus & Paula Pires (eds)

Impact of European knowledge on the development of reinforced concrete in the Russian Empire

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ABSTRACT: As a part of the wide research field regarding the introduction of European knowledge to the Russian Empire and its adoption and implementation, this paper shines a light on aspects of early reinforced concrete knowledge transfer. The development of reinforced concrete in Russia has been studied and described in Russian publications of the Soviet and later periods to a limited extent. However, the evident and substantial influence of European knowledge and the contributions of European specialists from France, Germany, Switzerland, and Austria has remained unexamined. Drawing on historical, technical, and periodical literature as well as on archival documents, this paper describes three different examples of knowledge transfer and their influence on the local development of reinforced concrete.

1 INTRODUCTION

The introduction of reinforced concrete in the Russian Empire was facilitated by the local availability of all of its constituent construction materials. The indispensable iron and cement industries had already been established in Russia before the first application of reinforced concrete was tested in 1886. In Russia, the science of iron extraction and processing had been developing for nearly two centuries before the introduction of reinforced concrete. Thus, at the time of the new method's introduction, the quality of Russian iron was suitable for use in reinforced concrete construction. The industrial scale production of cement had begun in 1856 with the establishment of the first cement factory in western Russia. Before the first reinforced concrete structure had been erected, the nascent cement industry had been maturing for about 30 years, and a total of seven cement factories had been founded. Before it was used in reinforced concrete construction, cement was used for mortar, plaster, and in the construction of unreinforced concrete structures in the Russian Empire.

Information about the use of reinforced concrete in the Russian Empire first appeared in technical literature in 1859. Two decades later, practical information concerning the use of reinforced concrete was brought to Russia by foreign and later by Russian specialists who went abroad to participate in professional meetings. The strongest proof of the importation of knowledge concerning European approaches to the use of reinforced concrete into the Russian Empire are the patents filed by Europeans and the evidence of the application of certain construction methods. The description of the three most influential reinforced concrete construction methods imported by foreigners is the main subject of this paper.

2 IMPORTED METHODS

2.1 *The Monier system*

A patent filed in 1878 in Russia by a French gardener, Joseph Monier (1823–1906), was the first and one of the most influential construction methods introduced in the Russian Empire. As Monier was not proficient in Russian, the local civil engineer, J. Armango (? - ?) submitted the application to the proper authorities on his behalf. After having been revised for two years by different institutions, the patent was eventually granted in December 1880; the patent gave Monier the rights to the method for five years. In contrast to his German patent of the same year that introduced limited construction elements such as pipes and buckets (Figure 1), the Russian patent described a variety of construction elements composed of a mesh of iron bars enveloped in concrete that could be deployed in

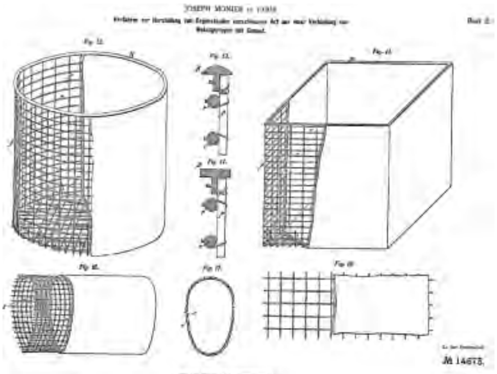

Figure 1. The patent Monier filed in Germany in 1880 (Kaiserliches Patentamt Nr. 14673).

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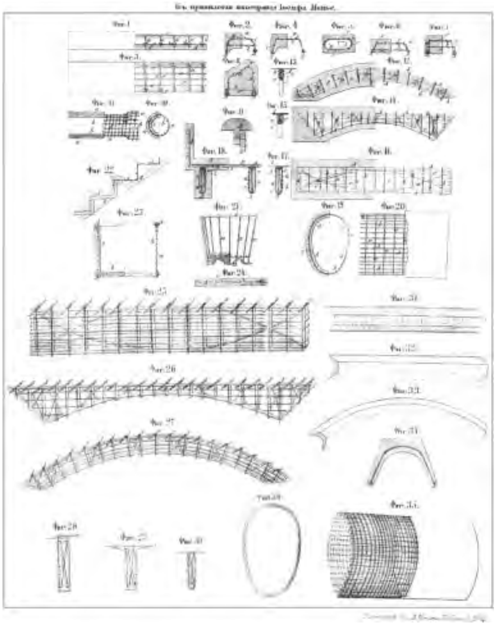

Figure 2. The patent Monier filed in Russia in 1880 (Department Torgovli i Manufaktur 1883).

a variety of structures. The variety of flat and curved slabs in his patent determined the design of the corresponding elements in the system. The patent shows a great attention to detail and clearly demonstrates the simplicity of the described method's implementation (Figure 2). Since the construction method was not applied by Monier within one year, the patent expired. Consequently, the technology could be used by members of the public without restriction. Despite this fact, no immediate local monopolization of this innovation materialised.

The first application of reinforced concrete associated with the Monier system in the Russian Empire occurred in 1886. In that year, the engineer Rostislav Pavlovič Sablin (1851–1905), and the architect Aleksandr Lavrent'evič Auber (1835–1898), were commissioned to construct the slaughterhouses in the old capital of Moscow. They conducted a series of loading tests on slabs and vaults intended to be designed for the slaughterhouse buildings. The design of the samples used in these loading tests is similar to that of the samples used in loading tests conducted a few months earlier in Berlin. This similarity can be explained through the cooperation of the Baltic-German engineer, Rudolf Johannsen (1850–1920), who might have been aware of the German tests. The list of participants at the *Haupt-Versammlung des Deutschen Beton-Vereins* (General Meeting of the German Concrete Association) – an important conference dedicated to reinforced concrete in Germany – shows that he had attended their meetings. Johannsen began working at a Moscow-based trading house owned by a Baltic-German man named Julius von Hueck in 1885. The trading house was responsible for the production of the samples for the loading tests. In the following years, this company constructed the slaughterhouse buildings.

Figure 3. The official load tests that were held in Saint Petersburg in 1891 (Akcionernoe Obščestvo 190).

Von Hueck's company employed the Monier system primarily in industrial buildings and to a lesser extent in public buildings. The company's attracted the attention of a Berlin-based construction company, *AG für Monierbauten*, which applied the Monier system during the same period. *AG für Monierbauten* decided to invest in the trading house in Moscow in 1890. The application of the Monier system was such a success that it warranted the creation of a new construction company. The construction branch of the trading house became an independent construction company, *Akcionernoe obščestvo dlja proizvodstva betonnych i drugich stroitel'nych rabot* (Joint-stock Company for Concrete and Other Types of Construction), on 9 April 1891. In November of that same year, the company carried out official loading tests in Saint Petersburg and invited representatives of different authorities and ministries to observe the tests (Figure 3). This event resulted in an increase in commissions throughout the Russian Empire.

The high costs for this event and the customs war waged between Russia and Germany between 1893 and 1894 led to the disintegration of the construction company's business relationship with the Berlin company in 1894. However, the company in Russia continued to apply the system independently. After Artur Ferdinandovic Lolejt (1868–1933), another employee of the company, presented the Monier system at the 2nd *S"esz Russkich Zodčich* (Congress of Russian Architects) in Moscow in 1895, the method gained notoriety among Russian architects.

The company had gained enough experience to begin building more complex structures. The company's expertise was on display at the expo in Nižnij-Novgorod in 1896 (Figure 4). The company constructed the longest reinforced concrete bridge in the Russian Empire at that time. The design of the bridge was reduced to essential constructive elements in reinforced concrete and had a span of 32 m. In contrast to the bridge structure, its two side pavilions were lavishly

Figure 4. The bridge at the expo in Nižnij Novgorod in 1896 (Akcionernoe Obsščestvo 190).

decorated with mouldable concrete in Baroque style. In 1896, the company also gave up the Monier system designation and replaced it with reinforced concrete in its catalogues.

In March 1899, at the 6th *S"ezd russkich cementnych technikov i zavodčikov* (Congress of Russian Cement Technicians and Manufacturers, abbreviated as the Russian Cement Congress) Johannsen gave a speech in which he mentioned the development of reinforced concrete in the Russian Empire. His lecture attracted the attention of influential representatives of the local construction industry and the government. In June of that same year, the Ministry of Communications approved the use of the Monier system in railway and road system construction projects.

2.2 *The Hennebique system*

The second construction method presented in this paper was invented by a French bricklayer, François Hennebique (1842–1921). The system's foundational method for combining iron and concrete to produce ceiling structures was patented in 1886 in Brussels. Over the following decade, this idea was developed into a complex and elaborate skeletal structure composed of monolithically attached columns, beams, joists, and slabs. This construction method was spread by Hennebique's world-wide professional network, which reported to a central office established in 1897 in Paris. The network included the agents – the official representatives of the Hennebique system and the concessionaires – as well as local engineers and contractors who were allowed to apply the construction method. The local engineers would send their projects to the local agents. The local agents would design the desired structures and send the drawings and calculations to the office in Paris for approval.

The first agent of the Hennebique system in the Russian Empire was a French engineer, Paul de Monicourt, who established an office in south-western Ekaterinoslav (today Dnepropetrovsk) in 1898. The favourable social, material, and logistical conditions in the region enabled the dissemination of this construction method. His first clients were the French-speaking directors and employees of local industrial companies.

Figure 5. A road bridge in Trituznyj Chutor, erected in 1902 (Černomorskoe Stroitel'noe Obsščestvo 1906).

Within two years of the beginning of his employment at the agency, he succeeded in establishing a network of local concessionaires in Ekaterinoslav, Odessa, and Moscow. During this time, he met a Swiss chemical engineer, Gabriel Egger (1867–1904), who also became an agent of the Hennebique system in the Russian Empire. Egger's efforts spurred an increase in bridge construction in the region. The majority of these newly erected bridges were road bridges in rural areas of Ekaterinoslavskoe Zemstvo. These bridges were a sustainable alternative to the region's traditional wooden structures. Icebreaker structures were attached to the piers of the bridges (Figure 5).

The expansion of the Ekaterininskaja Railways pushed the Russian engineers to search for sustainable construction methods. The Hennebique system, which had previously been applied in the region, sparked the curiosity of the engineers of the Railways. The Hennebique agents were commissioned to build three bridges. The Railways engineers thoroughly studied these bridges. After a short period of cooperation, the Railways engineers were able to design the bridges on their own. Since there was no patent for the Hennebique system in the Russian Empire, the engineers were able to apply the construction method without restriction. The Russian engineers had made further improvements to the construction method. They constructed grand structures, including the longest railway bridge at that time. It had a span of 6.4 m (Figure 6). These circumstances deprived the agents of the exclusivity in bridge construction that they had enjoyed in this region.

Meanwhile, the agents further expanded the network of the Hennebique system in the Russian Empire by establishing another office in Saint Petersburg and recruiting more concessionaires. Independent of the situation in Ekaterinoslavskoe Zemstvo, the agents were successful in controlling the use of the system in the rest of the Russian Empire, especially in its capital, by forming a partnership with a humble local construction company: *Cemento-Betonnoe Proizvodstvo M.A. Čusanov* (Cement and Concrete Manufacturer of M.A. Čusanov). The agents continued to improve upon the design of structural elements for buildings using the

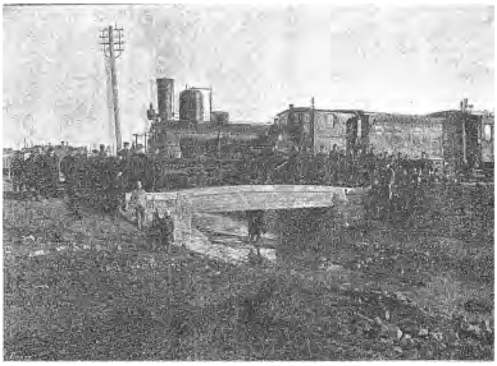

Figure 6. The bridge at the Mariupol’ Port Station, 1907 (Mal’cev 1908).

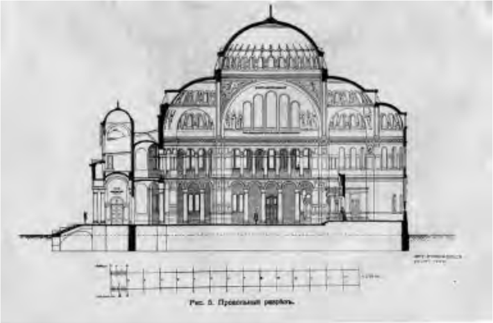

Figure 7. Longitudinal section of the Cathedral of Poti, Georgia, 1908 (Kurilenok 1908).

principles of the Hennebique system; they expanded their repertoire by venturing to construct domes.

De Monicourt and Egger were looking to establish connections with members of local professional networks. They published ads for the Hennebique system in the technical journal in Ekaterinoslav and took part in the most important reinforced concrete meeting, the Russian Cement Congress in Saint Petersburg, where they brought the Hennebique system to the attention of construction professionals and governmental institutions. Their participation in the event provided them with the opportunity to publish in the annex of *Zodčij* (The Architect), the Russian Empire’s most significant architectural journal. The focus of the annex was mainly on the production, application, and testing methods of cement.

The death of Egger in 1904 led to the demise of the Hennebique network in the Russian Empire. It forced de Monicourt to collaborate with a construction company established in Saint Petersburg, *Černomorskoe stroitel‘noe obščestvo* (Black Sea Construction Company). The company took over the application of the system and became the only Hennebique agent in the Russian Empire. Within a few years, this company had improved upon the system to the point that it could be used to create complex structures entirely out of concrete (Figure 7).

Figure 8. The construction site of the bridge near Černigov (von Emperger 1911).

2.3 *The Visintini system*

A reinforced concrete method invented by the Austrian technician, Franz Visintini, was not as widely used in the Russian Empire as the two previously mentioned methods, but it was used in the construction of a significant bridge in the Russian Empire. Franz Visintini filed the patent for his method in the USA in 1903. It introduced truss girders of different configurations that could be used as horizontal or vertical construction elements. The exact same patent was filed in the Russian Empire in that same year, but the patent officers did not process it. Five years after he had attempted to patent it, Visintini had the opportunity to present his construction method in person in front of the 12th Russian Cement Congress in Moscow. This led to the revision and granting of the patent within two weeks of his presentation. These circumstances aroused the interest of local engineers. At the same congress, Visintini met Wiliam Filipovič Jakobi, the owner of a Moscow-based construction company who would become a representative of this method in the Russian Empire. The company used Visintini’s method in several construction projects mainly located in Moscow and its surroundings.

One of the most significant structures in the Russian Empire (and in Europe) built using Visintini’s method was the bridge over the Desna River built near Cernigov (Ukraine) to facilitate travel to Kiev (Figure 8). It had four sections. The builders constructed the sections in wood and reinforced concrete in an alternating sequence. It had a total length of 635 m and a width of 8.5 m. The spans of 16 to 17.2 m between the piers in the reinforced concrete sections were connected using five truss girders. The girders were prefabricated on site on the river bank and were rolled along the bridge to the appropriate position, where they were placed on the piers (Figure 9). In order to make a rigid structure, the upper chords of the truss girders were monolithically attached to the horizontal slab above. In addition, every pair of truss girders was connected using five slabs, which were monolithically attached to the vertical bars. The construction of the bridge lasted two years and was completed in 1911. Due to its complex construction, in particular, the combination of wood and reinforced concrete, this bridge was a very fragile structure. However, as one of the contemporary engineers wrote, the

Figure 9. Setting up the truss girder (Hess 1911).

precious result was not the bridge but the progress that its construction led to.

3 CONCLUSIONS

The description of the three most notable construction methods in reinforced concrete introduced and applied in the Russian Empire reveals the context of the knowledge transfer occurring during this period. The basic precondition for the introduction of these methods was the existing, international, professional network in the Russian Empire. In the beginning, this network was composed of local building experts who supported foreign specialists. This network also included foreign clients residing in Russia who had a familiarity with this new technology and an interest in employing it.

The cautious nature of Russian engineers toward the application and adaptation of new technologies caused the development of reinforced concrete in the Russian Empire to occur after its introduction and use in Europe. Moreover, this delay made seeking patent protections for this construction technology a fruitless effort.

An important precondition for the adoption and application of reinforced concrete was the existence of Russian professional networks. Local construction companies were able to employ this new technology once they were made aware of it. Reinforced concrete construction technology was discussed at different professional meetings that supported its expanded use in the Russian Empire. The most influential platform for the dissemination of reinforced concrete knowledge was the Russian Cement Congress, which was initially established as a forum for the exchange of knowledge about the production, testing methods, and application of cement. The participation of representatives from influential governmental institutions, such as the Ministry of Communications, in this congress resulted in the acknowledgment of reinforced concrete and the approval of its use in the Russian Empire.

After the introduction of this new technology, the Russian development of this imported construction method took place. The buildings described in this paper attest to the fact that the local development of reinforced concrete methods surpassed the heights reached in other countries both literally and figuratively.

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History of Construction Cultures – Mascarenhas-Mateus & Paula Pires (eds)

Metal structural work embedded in concrete for slender vaults, 1880–1910

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ABSTRACT: During the two decades around the turn of the 20th century, a particular kind of vaulted roof became widespread: it had a metal structural work embedded in concrete and consisted of ribs and meshes of reinforcements strung between those ribs. This structural work was based on the criteria for metal vaulted roofs during the second half of the 19th century; it ensured the static equilibrium of large roofs and reduced construction time and costs by functioning simultaneously as a supporting framework for centering. Embedding it in concrete made this metal structural work a crucial point of reference during the 1920s in the production of the Dyckerhoff & Widmann company’s vaults.

1 SLENDER VAULTS AND BUILDING TRADITIONS

In the architectural panorama of the 19th century, traditional domes and vaults were still used for the roofs of both public and industrial buildings. The emergence of new materials that reduced construction time and costs did not result in the disappearance of such traditions but rather studies and research programs that sought the technical means to ensure their survival. At the same time, however, the new materials modified the traditions, reducing thicknesses and producing an ideal dematerialization that turned vaults into evocative figures. While some vaults were still built in masonry, there was at first a widespread adoption of metal structural work enclosed within a variety of materials. This was followed in the second half of the 19th century by a mixed structure composed of concrete in which metal bars, arranged to form a geometric mesh of reinforcements, were embedded. The success of this structure in vaulted roof construction from the mid-19th century can be ascribed to its characteristics: compared to metal structural work, it is fire-resistant and monolithic; compared to masonry, it is more slender and lighter, with limited construction time and costs. It is no accident that some vaulted structures initially planned with masonry instead used this mix of concrete and metal reinforcements precisely to reduce costs. And yet in the early phase of experimentation and research into the development of slender vaults using the new system of construction, brickwork and metal structural work were still used; these were integrated with reinforcements and concrete, producing a peculiar kind of roof whose configuration was derived from brickwork techniques and metal structural work. At a time when the structural behavior of vaulted roofs built of concrete with reinforcements was poorly understood, engineers and builders put their trust in what had become well-established materials and techniques whose every aspect they could control, from structural behavior to methods of calculation and construction on site.

At the end of the 19th century, the roofs executed in concrete with reinforcements were domes and vaults. In industrial buildings, these had depressed profiles and were devoid of any kind of ornamentation or cladding (Lampariello 2018a); in monumental works, they had rounded profiles and facings. Either could be smooth or have cells and ribs. In smooth roofs, metal mesh was embedded in a thin layer of concrete, which was sometimes combined with a brick vault, a technique employed through the 1910s at least (Czymay 2018). In vaults consisting of cells and ribs, however, the cells were constructed with concrete reinforced with interlaced bars, like smooth vaults. The ribs were made out of a variety of materials, such as meshes of metal bars embedded in concrete, bricks and combinations of those materials, as in the vaulted roofs built by Paul Cottancin (1865–1928) using his patented construction system called *ciment armé* (Lampariello 2018b). In other cases, the ribs consisted of section irons with different shapes. Together with the meshes that reinforced cells, rib section irons constituted a special form of metal structural work embedded in concrete. Thus, the system of construction that had already proved capable of replicating traditional vaulted roofs, ensuring both a light and slender structure that was quick and cheap to build, was then articulated and embedded in concrete to give it the property it lacked: fire resistance. Not coincidentally, in the construction of horizontal structures, the use of a kind of slab made of metal beams embedded in concrete, either with or without reinforcement, proliferated during the second half of the 19th century.

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In late 19th-century vaulted roofs, rib section irons were arranged in a geometric pattern or placed at the intersections of cells. They defined empty areas in which a metal mesh was inserted or panes of glass were set to create openings without the addition of other frames. Tie beams were combined with section irons through vertical rods, forming a system comparable to that of the metal truss. Other section irons were added at the springers of the vaults. Thus, the section irons and mesh were embedded in concrete so as to create a continuous enclosure with ribs in relief or with smooth upper and lower surfaces. In the latter case, the section irons constituted invisible ribs, as would be explained in early 20th-century manuals devoted to construction in concrete and reinforcements (Berger & Guillerme 1902: 329–30). The configuration of metal structural work, with section irons and mesh embedded in concrete to produce ribs that were either in relief or invisible, proved decisive in defining a building's character. The aim was to evoke Gothic, Romanesque or baroque roofs, depending on the various traditions of construction, to express the style that architects were trying so hard to develop.

Metal structural work produced a system of construction defined by two components that played different static roles but were embedded in the same cast of concrete to form a monolithic roof: a load-bearing component (the ribs) and the enclosure (the cells). While the latter contributed to the former's overall stiffening and transfer of forces, their different roles were confirmed by early 20th-century scientific publications: ribs comprised the *carcasse*, *ossature*, "skeleton" and "framing" (Anonymous 1905, 1908b; Berger & Guillerme 1902: 405; Christophe 1902: 40) and cells the *hourdis*, a term that generally referred to a secondary structure of enclosure (Berger & Guillerme 1902: 438). It is significant that the distance between the section irons of the ribs was sometimes so short that the presence of reinforcements in the cells' concrete was not even necessary.

This vault's peculiar nature, derived from the tradition of vaulted roofs and relying on metal structural work enclosed within a variety of materials, is confirmed by its method of calculation. Taken from the tradition of working with metal, the method used the principles that had already led to the design and construction of vaulted roofs with metal structures over the course of the 19th century (Figure 1). So in roofs with metal structural work and concrete what was calculated was the structural function of the ribs' section irons, not that of the concrete with reinforcements of the cells. Moreover, while other mathematical formulae were able to calculate the structural behavior of vaults even when loads were asymmetrical, they were too complicated to be applicable in building (Strutt Rayleigh 1877–78; Hough Love 1892–93).

So, in spite of the fact that the system made up of metal structural work and concrete was generally called "reinforced concrete" in scientific publications at the turn of the century, it had in reality a different structural function and composition. It is no coincidence that at the beginning of the 20th century terms other than "reinforced concrete" were being proposed to more accurately refer to the roles played by metal structural work and concrete in this kind of roof. The search for technical accuracy also involved finding terms for the vaulted roofs that had been transformed into evocative figures through the embedding of metal structural work in concrete, for which new definitions were proposed in the same period. If it is possible to find indications of the appearance of a structure in reinforced concrete, however rudimentary in terms of the arrangement of the reinforcements, laid out in geometric meshes insensitive to static loads, it is in the cells. Not coincidentally, they were destined to play a crucial role in the evolution of slender vaults.

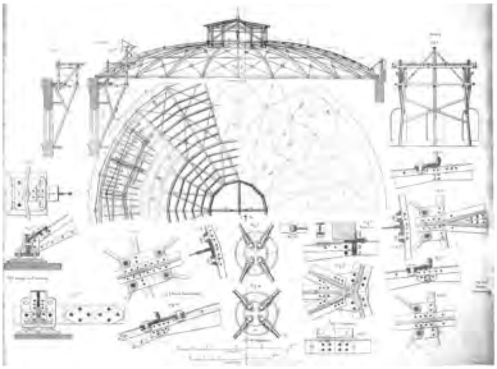

Figure 1. Johann Wilhelm Schwedler, Gasbehälter-Hause, Berlin, 1866 (Schwedler 1866).

It was the size of the roof that made the presence of ribs necessary at the end of the 19th century. Knowledge of reinforcements' structural function and of mathematical calculations applicable to vaulted roof construction had not yet grasped that reinforcements could be the sole means of stiffening vaults of over 7 m (Kurrer 2018: 722–31; Schöne 1999). At the same time, in slender vaults consisting of metal structural work and concrete, rib section irons played a role in the construction phase. Exploiting the advantages of construction in metal, the ribs were in fact fabricated on the ground and used as centering structures for casting concrete. In the calculation phase, therefore, the ribs were given dimensions that would ensure the roof's stability and strength not only after its completion (to resist wind and withstand its own weight and that of snow) but also during its construction (to support centering and workers). And yet during vault construction the ribs were in any case supported on temporary structures to avoid the various stresses, such as those generated by workers' activity or changes in temperature, resulting in the ribs' failure to adhere to the concrete (Christophe 1902: 426–27). Thus, the choice of ribs made of section irons rather than a mesh of reinforcements was based on the construction time and costs saved by assembling section irons on the ground to form a prefabricated structure. When necessary, the mesh of reinforcements was combined with bricks, which were also used in late 19th-century material to stiffen large vaulted roofs. Like the definition of static equilibrium, the question of construction was fundamental and would remain the focus of research aimed at finding the most rapid and economical system for building vaults. By the late 1910s section irons would for the most part be replaced by a greater number of bars embedded in the concrete, forming other ribs, and at times fabricated on the ground to serve as centering supports during cell construction. In the 1920s, however, following experiments on a new form of metal structural work, a science of construction that had by this time mastered mathematical calculation and tensile strength tests developed a structure that relied entirely on concrete with reinforcements arranged to cope with static forces. These reinforcements, arranged in a geometric mesh and embedded in cell concrete to create the secondary structure of metalwork in turn-of-the-century buildings, would become the fundamental components of smooth and continuous reinforced concrete vaults, devoid of any ribbing.

2 FROM TRUSSES TO SECTION IRONS: THE WORKS OF WAYSS, KOENEN AND COIGNET

Gustav Adolf Wayss (1851–1917) and Matthias Koenen (1849–1924) played a crucial role in the spread of the use of metal structural work for large concrete vaulted roofs. In 1887, after developing calculation formulae and testing the tensile strength and other properties of the combination of reinforcements and concrete patented by Joseph Monier (1823–1906), Wayss and Koenen published the first technical-scientific book on its use: *Das System Monier* (Wayss 1887). This work gave precise directions for the development and improvement of vaulted roofs in concrete with reinforcements, illustrating calculation methods, construction processes and a variety of applications. The use of metal structural work derived from a recognition of the decisive value of adding reinforcements to concrete, referred to by Wayss and Koenen as *Eisengerippe* (iron ribs) with a *Cementumhüllung* (cement covering).

The ribs took the form of trussed arches, made up of section irons with different shapes riveted together, and were positioned at the intersections of the cells in cross vaults. In domes, a relevant indication was given for the arrangement of the reinforcements along the meridians and parallels, which would find direct application in the distribution of the ribs. This geometry was determined by the tradition of using metal structural work in construction beginning with the simplified system of structural calculation based on graphical design principles developed by Johann Wilhelm Schwedler (1823–94). These principles had found extensive application in the erection of metal domes with a primary structure arranged along meridians and parallels with a secondary, stiffening and bracing structure arranged diagonally (Schwedler 1863, 1866). Cardboard or zinc sheets, or the Rabitz panels used as disposable formwork for pouring concrete (Rabitz 1878), were fixed to the arches with wire via the same artisanal technique required to attach the reinforcements of the metal mesh to arches. The system of resistance to thrusts was provided by traditional means: buttresses ranged along external walls. The arches, although embedded in the concrete with the reinforcements, still formed ribs along the roof's lower surface. Their profile was modeled to make the structure look like traditional vaults, such as the ogival ones with multiple ribs of the Evangelical church in Hagen (Figure 2). A close-knit wire mesh, added to the reinforcements to create Rabitz panels as disposable formwork, appears in the detailed drawing of the vaults' metal components. When vault size was very large and its function was beyond that of a simple roof, serving as a supporting structure of a floor slab, the roof was divided into a series of trusses and small vaults, as in the dome of the Alberthalle at the Krystallpalast in Leipzig. Nothing could be seen of the trusses apart from their flat lower surface, combined with a geometric pattern of squares painted along vault edges to make the whole roof look like a massive traditional masonry structure. Ribs in the form of truss structures combined with vaults made of concrete with reinforcements as enclosures would continue to be used in the construction of large roofs at least up until the first decade of the 20th century.

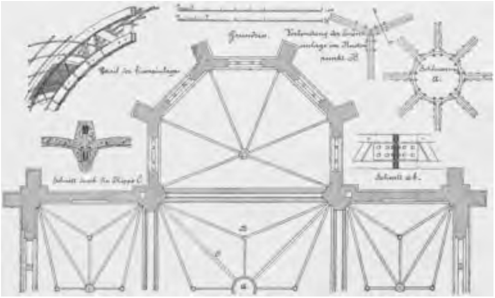

Figure 2. Gustav Adolf Wayss, Evangelical Church, Hagen, n.d. (Wayss 1887: 84).

In the technical and scientific history of slender vaulted roofs with metal structural work and concrete, ribs underwent an important evolution when, as early as the 1890s, truss structures began to be replaced by a kind of construction wholly reliant on simple section irons. This was a significant step in the slow process of understanding the structural function of metalwork combined with concrete. The use of section irons would lead to important modifications in the way that the system of ribs and mesh of reinforcements were joined together, in a shift toward an increasingly industrialized mode of construction in which the section irons were often perforated so that the reinforcements could pass through them. The protagonists of this phase were Josef Melan (1854–1941) on the one hand; and Edmond Coignet (1856–1915) and

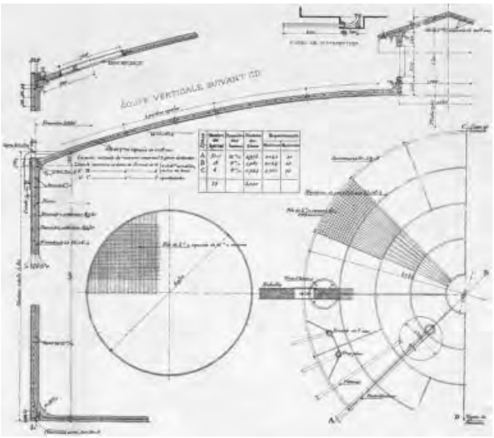

Figure 3. Edmond Coignet, cistern, Port de Lorient, Caudan, n.d. (Berger & Guillerme 1902: plate III).

the Wayss & Freytag, Beton- und Monierbau Aktien-Gesellschaft, Heilmann & Littmann, Chassin, Société des Ciments de la Porte de France and Elzner & Anderson companies on the other. All would use such metal structural work to build churches, museums, cisterns and storehouses. However, Melan used I-section irons in line with an invention he had patented that would produce solutions confined to its application. The others came up with a broad range of works in which the shape of the section irons varied from channel to T and angle irons. Their experiments followed in the footsteps of the studies carried out in the 1890s by testing tensile strength and calculation formulae relating to the configuration of concrete metal reinforcements. Not coincidentally, it was in just this period that such reinforcements began to assume different shapes from those of Monier's mesh, becoming independent section irons with a variety of shapes (I for Hölzer, T for Wünsch, etc.). It was during these experiments that new definitions were used in scientific publications for such roofs, which were so different from traditional ones in their substance and structural function that they could no longer be called vaults. *Betonhaut* (concrete skin) and *schale* or "shell" were the emblematic names adopted for roofs so slender that from this time on they were viewed as skins reinforced with metal structural work or as rigid membranes (Anonymous 1908a, 1908b; Zöllner 1906). Even the roofs' material became the subject of critical reflection, to the point of discussing a new denomination that captured the different static roles of the metal structural work and concrete: *Beton-Eisenbaues* (concrete and iron structure) was proposed, as an alternative to *Eisenbeton* (reinforced concrete) (Anonymous 1903a).

The domes built by Coignet from the mid-1890s onward, with diameters greater than 8 m, were depressed for cisterns (Caudan) or hemispherical for public buildings (Suez Canal Company headquarters at Port Said). The ribs were formed from channel section irons ranged along the lines of the meridians and parallels – 16 × 4 cm (Figure 3). They were defined as "*carcasse rigide qui sert de gabarit*" ("a rigid shell servings as a frame") or "*ossature*" ("skeleton") (Berger & Guillerme 1902: 405). It is possible that this kind of roof was designed as a form of flat-slab structure. A similar metal structure was embedded along the vertical walls on which the roofs rested and at their springers, to resist the thrusts. The cells between the section irons of the ribs were made from a mesh of bars with a diameter of 4 mm and a spacing of 8 cm. Mesh and rib density was not constant throughout the roof, as the number of meridians decreased toward the top where the shear stresses were lower than at the springers. None of the diagonal ribbing of the sort envisaged in metal domes constructed according to Schwedler's principles was present: the cells performed the function of stiffening and bracing the *carcasse* or shell. In the light of its high tensile strength, metal structural work embedded in the concrete became widely used in industrial constructions like those of Chassin (Triel), even where the stresses were strong, as in the underground domes of the tanks built by the Société des Ciments de la Porte de France (Belley).

What was emerging at the beginning of the 20th century was a kind of structural solution capable of spanning ever greater distances with ever more reduced thicknesses thanks to simple section irons of slight dimensions, which could also perform other functions such as supporting lanterns or anchoring hanging slabs. Among the various constructions of this kind, which included the domes of Antwerp railroad station and some pavilions of the Cincinnati Zoo, the most daring were built in Munich between 1900 and 1907 at the Armeemuseum (16 m in diameter) and the Department of Anatomy (22 m in diameter) by the Eisenbetongesellschaft mbH company, formed in that city after the merger of Wayss & Freytag and Heilmann & Littmann (Pogacnik 2009). The development of the Armeemuseum was overseen by Emil Mörsch (1872–1950), chief engineer of Wayss & Freytag and Ludwig Zöllner, general manager of Eisenbetongesellschaft mbH, while that of the Department of Anatomy was overseen by Zöllner alone. The design of both domes followed Schwedler's principles with ribs made from T section irons along both the meridians and the parallels, and with channel and angle section irons inserted in the springers and at the top, where an oculus was set at center of the domes (Zöllner 1905). So in this kind of vaulting the empirical criteria of the metal structural work tradition, established on the basis of graphical principles and accompanied by simplified formulae of calculation, were still applied (Mörsch 1909: 251).

The Armeemuseum building's monumental character motivated the choice of two superimposed domes, both constructed using metal structural work embedded in concrete: the internal dome as a closure of the space and the other as a symbol that stands out on the city skyline, reaching a height of 57 m thanks to its rounded profile with a lantern on top (Figure 4). The gap between the two roofs is not the inevitable consequence of the technical means of linking them,

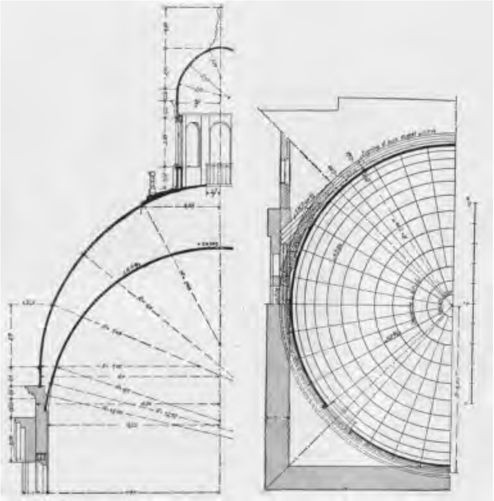

Figure 4. Eisenbetongesellschaft mbH, Ludwig von Mellinger, Armeemuseum, Munich, 19 00-05 (Mörsch 1909: 250).

but a residual space between two envelopes. The configuration of the ribs of the outer dome was designed to balance the thrusts of the load of the lantern on top. Thus, the section irons are larger along the meridians (9 × 4.5 cm), which react to compressive stresses, than along the parallels (8 × 4 cm), which react to tensile stresses. In addition to the channel section irons, a thickening of concrete was added to the springers in the form of an external rib. Rivets joined the section irons together so that the flanges of those on the parallels rested on those of the meridians. In confirmation that this system of construction was still indebted to the tradition of metal structural work, the stresses between these joints were treated in Mörsch calculations in the same way as any connection of pieces in a metal structure (Mörsch 1903). The mesh of reinforcements, uniform over the whole vault, consisted of 9-mm bars with a spacing of 10 cm. The 5-cm-thick layer of concrete did not completely conceal the geometry of the ribs, with the meridians coming to the surface and remaining visible on the underside of the larger dome.

The configuration of the ribs was strengthened in the depressed dome of the Department of Anatomy so that the ceiling of the microscopy room could be anchored to it. This meant reinforcing the section irons of the parallels.

They were formed by the juxtaposition of two angle irons (9 × 4.5 cm) riveted along the lower surface of the flanges of the meridians in such a way as to produce ribs that, although embedded in the concrete, appeared in relief on the underside of the dome where the ceiling hung by vertical rods. In order to increase the resistance, a diagonal arrangement of angle irons was added at the top.

Figure 5. Beton- und Monierbau Aktien-Gesellschaft, Wolf warehouse, Basel, n.d. (Christophe 1902: 212).

When the size of the vaulted roof was reduced, the ribs assumed the form of a single sequence of meridians like the L-shaped ones of Elzner & Anderson's Herbivora Building at the Cincinnati Zoo; the reinforcements consisted of twisted, square bars. As part of the quest to reduce construction time and costs, the formwork was disposable, consisting of a lathing of expanded metal embedded in two layers of hard plaster.

That metal structural work was preferred at the turn of the century for stabilizing large concrete vaults is confirmed by the solutions adopted for tunnel vaults. This kind of vault, produced by the company run by Koenen, Beton- und Monierbau Aktien-Gesellschaft, consisted of metal ribs composed of different parts, some embedded in concrete and others left in view, resulting in a type of roof that still did not meet the fire resistance requirement which concrete with metal reinforcements had been proclaimed to do (Figure 5). The section irons were concentrated at the springers, which not coincidentally represented a crucial detail to which various experiments would be devoted up until at least the 1930s. Channel or I-section irons were anchored in the masonry of the springers, bound together crosswise by tie beams with a circular or flat section; a sequence of vertical rods stopped the tie beams from bending by anchoring them to the vault.

In this configuration, the supports on which the roofs rested took on the form of continuous walls. More section irons were added at vault openings (Anonymous 1903c; Geusen 1907). The configuration of the system of resistance to thrusts could be modified to cover spans as wide as 25 m as well as to avoid the use of section irons and tie beams of ever greater size and quantity: the tie beams assumed an L-shaped profile and were arranged with a wide gap between them (6 m), while two more rods were added at the springers to bind each tie beam diagonally to the section irons in order to reduce the bending stresses. The system was known by the name of the company that invented it, F. Schlüter (Christophe 1902: 210).

3 THE MELAN SYSTEM

In 1892, with his patent for floor slab construction using metal I-beams and small vaults with a regular sequence of metal arches made of I-section irons embedded in concrete, Melan ushered in a system of construction that would become widely used for floors and vaults (Melan 1892). But the great strength displayed by structures using this system induced engineers and entrepreneurs to employ the invention not so much for building as for civil engineering; specifically, in bridge construction (Eggemann & Kurrer 2006). Just as for the domes built on Schwedler's model, Melan too made use of a "semi-empirical" method based on calculation formulae and graphical principles (Christophe 1902: 650). It was the Pittel & Brausewetter company of the entrepreneur Adolph Freiherr von Pittel (1838–1900) and the engineer Viktor Brausewetter (1845–1926) that acquired the patent license in the Austro-Hungarian Empire and Germany in 1892.

They tested the Melan system's load-bearing capacities as early as the summer of 1892 and throughout 1893. The 1892 tests were conducted on two 2-m-spanned vaults with a thickness of 8 cm and with 8-cm-high I-section irons located every 80 cm; the 1893 tests on a 4-m-spanned vault with identical thickness and I-section heights but with the latter located every meter (Melan 1893, Chemolli 2017). The results confirmed strength greater than that of concrete and metal mesh reinforcement vaults, which had been tested in Berlin in 1885 and in the Austro-Hungarian Empire in 1893. The Melan system's performance prompted Brausewetter himself to file a patent in late 1892 for concrete constructions with a *skelett* of metal tubes, generating a structure capable of integrating other functions (Brausewetter 1892), in line with Cottancin's contemporaneous research (Cottancin 1890).

The vaulted roofs constructed by Pittel and Brausewetter using the Melan system were mostly tunnel vaults with spans of over 10 m and with ribs at the springers and along the roof. To make the vault resistant to thrusts, metal tie beams and vertical rods left in view were generally introduced. The vault of the Arbeiterheim in Favoriten, built in 1903 in collaboration with the architect Hubert Gessner (1871–1943), a student and assistant of Otto Wagner (1841–1918), is emblematic in this sense. The vault spans 18 m and is 10 cm thick, with I-section irons each comprised of six pieces bolted together (Anonymous 1903b). At the springers, channel section irons were bound crosswise by pairs of cables tightened by screws. Vertical rods bound the tie beams to section irons along the vault. The closely packed arrangement of the section irons, located every 60 cm, contributed to the development of a main structure reliant on just those section irons, without the presence of a mesh of reinforcements. The cells between the ribs – excepting cells made of glass panes to serve as openings – were made of concrete to render the vault smooth on both lower and upper surfaces (Figure 6). The bottom flanges of the section irons were left visible and stood out against the white plaster applied to the concrete, giving them the appearance of seams between pieces of cloth (Lux 1903). The white color detached the concrete enclosure from the section irons, contributing to its awning-like appearance and demonstrating the Melan system's extreme lightness by evoking a textile without the need for additional facing – such as the Rabitz panels Wagner was then using for the dome of St. Leopold am Steinhof church. Even the lines of the glass panes in the openings were integrated into the roof's evocation of an awning thanks to the representation of fastenings in the form of rings, contributing to the generation of Semper's *Stil in den technischen und tektonischen Künsten* (Semper 1860–63). This "style" is entirely based on a metaphorical envelope delimiting space and whose principal characteristic was lightness.

Figure 6. Pittel & Brausewetter, Hubert Gessner, Arbeiterheim, Favoriten, Vienna, 1903 (Anonymous 1903b).

In order to find alternatives to the cables and vertical rods that guaranteed vault stability but were aesthetically problematic for monumental buildings, variants were studied. They envisaged the introduction of other building traditional elements such as the buttresses Wayss had used in the late 1880s. But it was again at the springers that the vault thickened significantly. In Innsbruck's Evangelical Church of Christ, built in 1905, the nave's ogival tunnel vault has I-section irons placed every meter, a dense mesh in the form of nine-millimeter bars, and a thickness of 7 cm that at the height of the springers doubles to contribute to static equilibrium (Von Perko 1907). At the buttresses, the section irons are embedded in the concrete to form ribs in relief all along the vault, contributing a monumental character. On the other hand, the choice to reduce the intersections between the cells of the ogival cross vaults above the transept and altar where other section irons were placed to edges without ribs produces a singular effect, poised between the evocation of Gothic roofs and Romanesque structural solutions.

4 CONCLUSIONS

After the experiments conducted at the turn of the century, a new chapter in the use of metal structural work embedded in concrete for building slender vaulted roofs began in 1922. Walther Bauersfeld (1879–1959), an engineer at Carl Zeiss, and Franz Dischinger (1887–1953), an engineer at the Biebrich branch of Dyckerhoff & Widmann and its technical director, built a dome in Jena that consisted of a main structure of rods with a rectangular section (2 × 0.8 cm) connected to form a spatial frame based on triangulation of a spherical surface (May 2020). The frame's origins are in the studies carried out by August Föppl (1854–1924), Vladimir Grigoryevich Shukhov (1853–1939) and Alexander Graham Bell (1847–1922).

By this time metal structural work had freed itself from any historical reference to traditional vaults or domes and assumed a geometric structure of its own for which a specific term had been found: *netzwerk* (Dischinger 1925: 362). Although the term alluded to a net, in reality it was a frame; that is, it was no longer divided into ribs and cells and endowed with a rigidity that allowed it to be used as a self-supporting structure whose parts could be assembled without centering. Consequently, it represented a continuation of the processes established with earlier metal structural work. The gaps in the *netzwerk* were closed with a mesh of bars and concrete sprayed on using the sprayed concrete technique called *torkretieren*. Out of this came a new form of *schale* whose antecedents Dischinger acknowledged were the roofs of the Armeemuseum and the Department of Anatomy (Dischinger 1928: 284–87). From the mid-1920s onward, however, the *netzwerk* was transformed into a temporary structure for use in the fabrication of vaulted roofs: a framework for wooden planks on which to place the metal reinforcements and spray the concrete, as in the conventional technique, which could then be dismantled and reused. This advance, first applied in tunnel vaults, was made possible by the studies of another of Dyckerhoff & Widmann's engineers, Ulrich Finsterwalder (1897–1988), which allowed the *netzwerk* to be replaced by an arrangement of the reinforcements to cope with structural stresses.

Photographs taken at Dyckerhoff & Widmann's construction sites mark a crucial passage in the understanding of the potentialities of metal structural work that went beyond engineering. Photographs of 1922's first *netzwerk* showed how the framework formed the roof structure, prior to attaching the mesh bars and embedding the whole in concrete, during the customary ceremony of construction with the workers and a bush on the top. Photographs from 1924 onwards show a different point of observation: a spectacular view from below of workers clambering over the *netzwerk* silhouetted against the sky, reflecting an understanding of the structure's spatial value prior to its enclosure in concrete. But while Dischinger saw a poetic dimension in the photographs of the new structures' construction (Dischinger 1925, 364), László Moholy-Nagy (1895–1946) used the same images to suggest the vision of a structure in space (Figure 7). Moholy-Nagy cropped the photograph of the *netzwerk* of the Berlin planetarium's dome (1926), thereby omitting the base of masonry, and rounded the upper border to configure a framework projected against the sky that expressed a new conception of space (Moholy-Nagy 1929: 235).

Figure 7. László Moholy-Nagy, photograph, 1929 (Moholy-Nagy 1929: 235).

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History of Construction Cultures – Mascarenhas-Mateus & Paula Pires (eds)

On horizontality in architecture: Robert Maillart, the Queen Alexandra Sanatorium and the evolution of the slab

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ABSTRACT: Robert Maillart's reputation is mostly based on his reinforced-concrete bridges that can be seen as statements of a reflected, rationalized and material-efficient use of the new composite material. At the same time, in his early career Maillart found himself in an environment that was strongly dominated by the Hennebique-system. Searching for a new spatial expression inherently linked to the material's properties he challenged the prevailing application of these systems that was based on inherited forms rooted in the principle of post and beam. During the construction of the almost forgotten masterpiece of the Queen Alexandra Sanatorium in Davos, Maillart collaborated with Zurich-based architects Pfleghard & Haefeli and used the Queen Alexandra Sanatorium in his quest for a new formal language in which *Armierterbeton* would be used as a horizontal material, thereby following its structural logic and creating a new aesthetic that would eventually attract Sigfried Giedion's attention.

1 INTRODUCTION

In his 2007 book *Light, Air and Openness*, Paul Overy enthusiastically expressed his fascination for the Queen Alexandra Sanatorium in Davos. Introducing it as one of the "most spectacular of early 20th century Sanatoriums" he refers to the building as "proto-modern" (Overy 2007) (Figure 1).

Indeed, this bright building resting above the valley of Davos appears to be a protagonist from the early modern movement.

Liberated from almost all ornament it is characterized by a flat roof, cantilevering terraces and a perforated honeycomb façade with huge openings that appears to inhale sun and air. As a matter of fact, the building is based on a design from 1907 and was completed in 1909, placing it way ahead of its time.

Figure 1. Photograph of the Queen Alexandra Sanatorium taken in 1908 (source: Schweizerische Nationalbibliothek, Eidgenössisches Archiv für Denkmalpflege: Archiv Photoglob-Wehrli EAD-WEHR-7989-B).

Nevertheless, during the time of its construction, the Queen Alexandra Sanatorium which is a result of collaboration between architects Pfleghard & Haefeli and engineer Robert Maillart for reasons yet to be revealed was not included in the architectural discourse. No architectural or construction journals let alone books mention the building and the only traces of its existence can be found in medical journals. At the same time the building gained a certain degree of attention during its second life thanks to Sigfried Giedion who mentioned it on various occasions. He introduced it as a paradigm for healthy architecture in *Befreites Wohnen* (Giedion 1929a), labeled it "the best Sanatorium" in an issue of "*Das Neue Frankfurt*" (Giedion 1929b) and presented it in "Space Time Architecture" in the context of the proliferation of reinforced concrete (Giedion 1941). Furthermore, the building is mentioned by Döcker who presents it on a whole page with two photographs and brief captions (Döcker 1929). Publications dealing with the work of Robert Maillart (Billington 1997; Marti & Honegger 2007) mention the existence of the building in subordinate clauses. Even with this certain degree of fame and the prominent advocates, no further study regarding the building's design and construction have been undertaken so far, leading to its exclusion from the discourse on the modern movement. Also, it turns out that Giedion never seems to have seen the original building. All his publications as well as the unpublished original material in his archive point towards him visiting the building in the 1920s. By that time, it had already been sold to the canton of Thurgau,

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was operating under a different name and had undergone several architectural changes that would dilute the once pristine structure.

Using unpublished original material this paper will outline how the Queen Alexandra Sanatorium is not only proto-modern but also a role model for construction principles at the verge of modernism. In a unique context the rather traditional architects were confronted with a demanding client who was challenging them to question their inherited design approach and partially leave it behind. Bringing in the unconventional engineer Robert Maillart turned out be a stroke of luck. Maillart used this building to pursue his quest for developing a new formal language based on the properties of the new material reinforced concrete.

1.1 *Methodology*

While secondary literature is rare and superficial, archives hold vast amounts of hitherto unpublished material. The estate of the architects Pfleghard and Haefeli in the archive of the GTA at ETH Zürich contains more than 200 architectural documents. The Staatsarchiv Thurgau in Frauenfeld houses the archive of the "Thurgauische Gemeinnützige Gesellschaft" which bought the building in 1922 and inherited more than 150 plans from the original operating company. Unfortunately, none of these plans contain information regarding the engineering work. While Robert Maillart's official estate also lacks material, Maillart's original drawings were eventually located in the archive of the private engineering company DIAG (Davoser Ingenieure AG). Juxtaposing the plans from these three sources allowed for a meticulous analysis of the construction process. At the same time the plans tell only one side of the story. The Wellcome Library in London possesses valuable material from the archive of the Queen Alexandra Sanatorium Fund. It is through the minutes of the meetings of the Local Board of Management (1200 pages) that one can fully understand and assess the drawings as well as learn about the network of actors who were driving the construction of the building.

2 A NEW MATERIAL AND ANCIENT FORMS

Billington has outlined how Maillart was driven by a "design view" which was the complete opposite to the prevailing "applied science" approach (Billington 1997). In Maillart's logic, the new material reinforced concrete would have necessarily called for an evolution of form as well (*ibid.*) Following the inherent properties of the material to sustain tension the formal consequence would have been a horizontalization of architecture with the replacement of post and beam through panes.

However, at the beginning of his career Maillart found himself in an environment dominated by the Hennebique system. According to Billington, Hennebique applied the new material in a similar way like steel and wood had been applied for centuries. Imitating the skeleton forms in reinforced concrete, the revolutionary aspect of Hennebqiue's work is seen in the monolithic execution of these formerly separate elements (Billington 1997). A similar statement was made by Maillart in the late 1920s when he was pointing out that working with one-dimension linear elements was a reference to working with the directional materials iron and wood. While not explicitly mentioning Hennebique's name, the description of a system composed of beams and joists that are then covered with a slab that is not treated as an individual structural element clearly points to the dominant system of the late 19th and early 20th century. This linear thinking was also reflected in the way these systems were calculated. Unlike in other engineering disciplines where slabs were calculated as structural elements, the slabs in the field of construction were abstracted into strips that could then be calculated as beams (SBZ 1926). Kurrer has also identified this weakness of Hennebique, pointing out that calculation method was still the same as in the seemingly replaced mixed systems (Kurrer 2002).

2.1 *A first mission in Davos*

As a matter of fact, Maillart gained an in-depth insight into the Hennebique system while working as chief engineer for Froté and Westermann between 1899 and 1902. Shortly after joining the company, he was involved in the construction of the Schatzalp Sanatorium in Davos where an Hennebique frame was applied on a large scale. While his involvement came too late to have any influence on the design and calculations he thoroughly observed the construction works (Billington 1997). More importantly it was this job that would help him establish a fertile connection with the architects of the project, Pfleghard & Haefeli, that would eventually bring him back to Davos.

2.2 *A fruitful environment*

In early 1905, Pfleghard & Haefeli delivered their first design sketches for the new Queen Alexandra Sanatorium for consumption in Davos. These sketches would be subject to several changes over the course of the next 18 months. Driven by the science-based desires of the client, Pfleghard & Haefeli developed an anachronistic chimera that was still reliant on traditional ideas of architecture but at the same time anticipated essential elements of the modern movement. Following the underlying medical paradigm, they created an architecture that emerged from the serial replication of a human being's minimal space: 58 south-facing cells with private outdoor spaces were strung together and stapled, creating the aforementioned honeycomb-appearance (Figure 2).

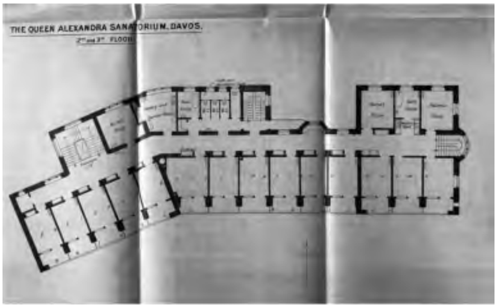

Figure 2. Typical floorplan of the 2nd and 3rd floor (source: Staatsarchiv Thurgau StATG 9’11, 5.0.0.1/0).

The idea of materializing these private outdoor spaces as well as the public terrace through a continuous cantilevering balcony had already been present in the first sketches when no engineer was involved in the project. Thus, it needs to be attributed to a dialogue between architects and client. Material-wise this concept resulted in the building’s vertical elements being built in a traditional brick construction using rubble stone found on site. At the same time, the horizontal elements (slabs and roofs) as well as the connecting staircases relied on the new material reinforced concrete.

2.3 *Calling for contractors*

In February 1907 calls for tenders for the construction of 5400 m^2 of reinforced concrete slabs including the necessary girders to be realized as piecework were published in various newspapers (SBZ call for tenders 1907). The resulting tenders were reviewed by Francois Schüle, head of the Federal Materials Testing Institute and one of the main characters behind the 1903 provisional norm for building in reinforced concrete. Schüle who was invited as an external expert found two of the tenders worthy of consideration (SANPT C 2 3). In late April, following the communication with those two firms, Pfleghard & Haefeli presented the following situation:

Mess. Maillart & Co., Zürich had reduced their price yet their offer was still CHF 9000 above that of the other company. At the same time, it was CHF 3000 beneath the original estimate of the architects. In their letter Pfleghard & Haefeli also explicitly highlighted that Mess. Maillart & Co. was very trustworthy and that this company would be able to carry out all the work themselves while the unnamed competitor was not known to them and would have to contract other firms to fulfil the work. Given these circumstances the architects recommended giving this work to Maillart – a decision which was approved by the board (SANPT C 2 3).

In many of his previous projects Maillart had shown reluctance towards the design proposals he had been presented with and had rejected them, often replacing them with one of his own. However, in the case of the Queen Alexandra Sanatorium he found himself in an environment that would allow him to pursue his idea of optimizing the aesthetics of the construction. The faith in Maillart appears to have been great enough to accept a considerably higher price. At the same time, a science-driven client evolved to be a strong co-designer acting outside of architectural dogmas. Last but not least, Otto Pfleghard turned out to be an architect with a strong interest in construction.

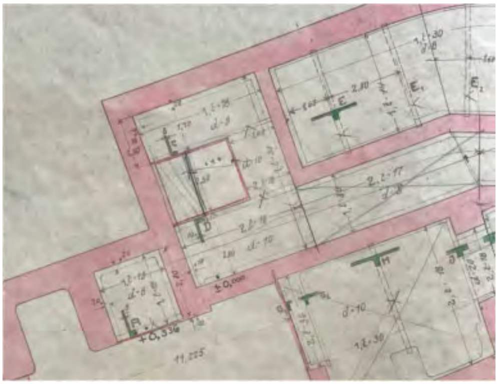

Figure 3. Excerpt from a drawing by Maillart for the basement of the Queen Alexandra Sanatorium showing the encoding. (source: Davoser Ingenieure AG DIAG).

3 DRAWING A BUILDING

Prior to discussing Maillart’s influence it makes sense to take a closer look at how Maillart drew his plan – in particular compared to Hennebique. Due to the nature of the business with plans being centrally drawn and eventually sent to local concessioners Hennebique had always prepared very detailed plans to guarantee a proper execution on site.

In contrast the organization of Maillart & Cie. allowed for a different concept. Not only did Maillart offer a one-hand-approach where he would conduct both the planning and eventual execution (HS 1085 1907–9). Billington also characterizes his personality as being almost obsessive, making the company highly dependent on him and his expertise (Billington 1997).

This organization directly translated into the plans that were encoded and required a certain degree of expertise to be deciphered (Figure 3). Beams were assigned a letter through which one could find them in the list of details. The thickness of the relevant part of the slab was indicated using the syntax d = x (thickness in cm). The reinforcement for the slab was stated in a syntax “y, t = xx” where y indicated the type of rod and xx the distance at which the rods were supposed to be installed.

It was this approach where concept and eventual execution were intrinsically linked that can be seen as prerequisite for an artistic approach and an anti-thesis for the idea of specialization.

Figure 4. The public cantilevering terrace in the ground floor that evolves into the curved *Consolenplatte* (source: Staatsarchiv Thurgau StATG 9’11, 10.4/0).

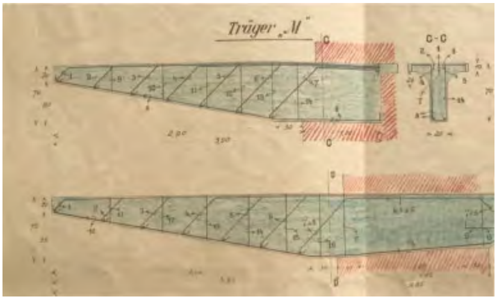

Figure 5. Cantilvering beam of the ground floor terrace (source: Davoser Ingenieure AG DIAG).

Figure 6. Detail of the *Consolenplatte* (source: Davoser Ingenieure AG DIAG).

4 MAILLART’S PATHWAY TOWARDS HORIZONTALITY

Starting in 1905 Maillart was entering a phase of his career in which he almost entirely gave up working on bridges and instead focused on buildings. Engagement with this kind of structure once again confronted him with Hennebique and it is here we can track an emancipation from this grandmaster of reinforced concrete. The starting point of this process can be identified in the construction of the Pfenninger factory in 1905 (Billington 1997). Following his paradigm of reduction and simplification Maillart stripped the Hennebique system of the joists while at the same time lengthening the span of the slabs (*ibid*.).

4.1 *Introducing the cantilever*

Two years later while working on the Queen Alexandra Sanatorium Maillart would refine this approach. Pfleghard and Haefeli’s design foresaw a large south facing terrace at the ground floor level. Over the course of the design process the columns carrying this slab had vanished with one exception, leaving Maillart with the task of implementing a huge accessible cantilevering element with a depth of 3.3 m. It is important to highlight that at that time Hennebique built cantilevers as continuous beams yet those were just canopies and not meant to carry loads of people. Drawing on the basic structural concept of the Pfenninger factory Maillart now pulled the slab out of the building. Up to 70 cm strong massive primary girders (Figure 4) penetrated the building envelope and carried the thin 10 cm strong slab of the terrace (Figure 5).

At the same time the transverse beams would disappear. He thereby managed to create an almost flying element that allowed for an unobstructed open-air space underneath where no vertical elements would cast shadows on the patients. At the same time this was not the peak of Maillart’s finesse.

4.2 *Hiding a bridge*

Billington has pointed out that Maillart’s proposal for the concert hall in St Gallen from 1906 had completely erased the girder by amalgamating a flat floor with an arch, thereby creating a bridge-like section. “If Maillart was not asked to build a bridge, he could at least slip one inside St Gallen’s largest monument to art” (Billington 1997). Just like in the case of St Gallen, Maillart also appears to have hidden his bridge in the Queen Alexandra Sanatorium. Starting at the risalit the main terrace evolved into a narrow walkway. Having strong resemblance to a ship it would take the flaneur around the corner providing a magnificent view over the town. Given the now reduced length of the cantilever Maillart sought to dispense with the joists as the last element conveying verticality. Instead, he designed a solely horizontal element which he called *Consolenplatte* (Figure 6). Formally resembling one half of a bridge these elements could cantilever as far as 2 m with a thickness of as little as 8 cm.

4.3 *Towards pure horizontality*

While the public terrace on the ground floor remained a singular element, its smaller siblings on the upper floors would become examples for the creation of a new architectural language emerging from a new material. Through disposing of the secondary beams, the patient’s room evolved into a plain shoebox where the smaller surface to the outside could be entirely opened.

Following the paradigm of the open-air cure, each patient’s room was equipped with a private outdoor

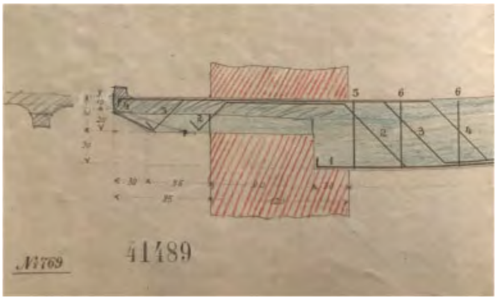

Figure 7. Detail of the slab in front of the cantilevering slab in front of the patients' rooms (source: Davoser Ingenieure AG DIAG).

Figure 8. Photograph of the cantilever in front of the patients' rooms (source: Staatsarchiv Thurgau StATG 9'11, 10.4/0).

space. Just like the large terrace on the ground floor these spaces – half-loggia and half balcony – emerge through a continuation of the interior slab. Maillart's first drawings both in plan and section show a scaled-down version of the public terrace's structural system with slab-carrying girders penetrating the envelope. However, Maillart appears to have been unsatisfied with the resulting appearance and began searching for a more elegant solution. In a hand-drawn correction he proposed the ingenious element where the interior beam rests on the brick column and then invisibly evolves into a cantilevering 12 cm strong slab with a stronger corner (Figure 7).

While detailing this balcony, Pfleghard & Haefeli developed a system of a wooden cladding that would not only conceal the articulated corner but would also visually decrease the thickness of the concrete slab, thereby contributing to the elegance of the overall appearance (Figure 8).

4.4 *Anticipating the Unterzuglose Decke*

Maillart achieved this effect through a different treatment of the slab's reinforcement as an individual structural element. In a traditional Hennebique system the slabs were equipped with reinforcement in one direction from secondary joist to secondary joist.

In contrast, in the Queen Alexandra Sanatorium Maillart applied a crosswise reinforcement which he would eventually refine in future years. Placing the reinforcement of the slab in both directions resembled the Monier traditional system from the late 19th century. Monier had introduced reinforced concrete slabs as one element in a mixed-material system that was complemented by iron girders and cast-iron pillars. At the same time those slabs were only meant for small spans and relied on a traditional system of beams to support. Furthermore, Monier distinguishes *Verteilungsstäbe* and *Tragstäbe* with only the latter being meant to sustain tension while the former was there to ensure that the *Tragstäbe* stayed in order (Weder 1906). Maillart however did not integrate this kind of discrimination and instead proposed equally important rods.

From this way of engineering a slab it is no big step to Maillart's *Unterzuglose Decke* that he would empirically test in 1908 and eventually patent in January 1909. When in 1926 Maillart discussed the *Unterzuglose Decke* he highlighted that through the cross-wise reinforcement the slab could withstand bending loads not only in the direction of the reinforcement but in all directions, effectively liberating it (SBZ 1926).

5 CONCLUSION

Robert Maillart's unique approach to engineering from the perspective of an artist and with a focus on empirical testing rather than relying on calculations found many opponents. While already possessing a reputation in the early 20th century he had to temporary leave the field of bridge construction, earning real money with building projects. The Queen Alexandra Sanatorium in Davos shows that even while temporarily abandoning his favorites, Maillart never stopped his quest for the development of a new formal language that would emerge from the new material. While being almost forgotten by history, the Queen Alexandra Sanatorium presents itself as a materialized testimony of this quest. Working in a unique environment Maillart and Pfleghard & Haefeli managed to create a building that anticipated the design language of the modern movement decades before it emerged. Gradually liberating the slab from all supporting elements and turning it into an individual structural element allowed for an entirely new approach to horizontality in architecture that was incredibly honest. For the first time the continuous horizontal element that was solely reflecting the loads had been introduced into the canon of architecture. An element that is now hibernating below layers that have emerged over the course of the last century.

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History of Construction Cultures – Mascarenhas-Mateus & Paula Pires (eds)

Hidden in the mix: How a regionally specific aggregate affected St. Louis Missouri's built environment

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ABSTRACT: When investigating finely crafted concrete, one might ask tradesmen about finishing techniques, vibration, water ratios, reinforcement placement, or formwork design. But aggregate? Most mix design assumes river sand for fines and prevalent limestone for aggregate.

Two family businesses, Winter Brothers Materials, and Simpson Materials historically have supplied the St. Louis area with Meramec river gravel through extraction from pit quarries and dredging operations. The city's curbs, sidewalks, bridge abutments, foundations, and viaducts dating back to Works Progress Administration utilize this gravel as aggregate in concrete. In the 1970s, brutalist buildings used the gravel for exposed aggregate, and most concrete architecture uses Meramec river rock as part of mix design. Recent employment includes two contemporary projects: as aggregate in the Pulitzer Arts Foundation by Tadao Ando (2001), and as exposed aggregate in precast panels for David Chipperfield's St. Louis Art Museum addition (2013). Aside from two publications (one in 1918, another in 1969) no scholarly research has discussed the importance of this material to the built environment of this Midwestern region.

1 INTRODUCTION

1.1 *Geology*

The Meramec River is a tributary of the Mississippi River. It empties into the Mississippi just south of St. Louis. The entire riverbed is lined with prevalent caramel colored chert gravel. The banks are comprised of 500 million-year-old Ordovician deposits along a seabed that eventually solidified into dolomite (a type of limestone), chert, and sandstone.

"A superabundance of magnesium, common to all sea water, combined with calcium carbonate sediments to create massive beds of the compound calcium magnesium carbonate; with pressure and time these beds solidified into the white rock dolomite. Blobs of jellylike silicon dioxide, meanwhile, became trapped within; they compressed into layers of extremely hard chert" (Jackson 1984, p. 5).

As the rivers eroded the banks the chert broke and fell to the bottom of the riverbeds where it collected. Some of the chert remains angular, glossy, and impermeable, while other pieces have eroded through the motion of the water, becoming rounded, textured and porous. (Figure 1).

Figure 1. Meramec river. (photo credit: author).

1.2 *Economic viability of meramec rock*

As settlers moved into the area, they searched for natural resources to exploit. Lead, iron ore, and red granite were found to the south of the Meramec river basin. Prevalent supplies of timber, sand, gravel, and silica existed within the basin. These commodities served industry and the building trades.

Infrastructure was needed to move these natural resources to St. Louis. A southern line of the Missouri Pacific was constructed through the Meramec River valley, running approximately 20 miles south of the Missouri Pacific train line along the Missouri River. This new line serviced quarries and timber operations between Labadie, Missouri and St. Louis. In particular, A large deposit of St. Peter Sandstone could be accessed by train in Pacific, Missouri. The deposit was high-quality silica; Pittsburg Plate Glass Company quarried it and transferred it by train to its manufacturing facility.

This location along the Meramec also provided access for gravel and sand companies to collect materials and send them to St. Louis. The Meramec supplies

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two commodities: sand and gravel. Size differentiates one from each other. Gravel is conventionally defined as larger than 2 mm and is used as aggregate for concrete, roofing gravel, back fill, and for landscaping. Sand is defined as smaller than 2mm. Meramec sand and gravel are collected in two primary ways: by quarrying pits in flood plains adjacent to the river; and through dredging operations, where dredging machines collect and transport rock onto barges in the water way.

In 1918, C. L Dake, a professor of geology at the Missouri School of Mines and Metallurgy, wrote the book "The Sand and Gravel Resources of Missouri." This reference provides a complete picture not only of sand and gravel use in 1918, but also careful definitions of their characteristics, how they behaved during use, methods of collection, and a full accounting of where they were located. In 1918, Dake describes the Meramec as one of the most important sources for gravel in the state "[The Meramec River] …is by far the most important gravel producer of the Ozark region. During the year 1913, the Meramec produced 14 per cent of the value and 17 per cent of the weight of the entire sand and gravel output of the state" (Dake 1918, p. 226).

Today most of the gravel and sand extraction is completed by two family businesses Simpson Materials Company, and Winter Brothers Material Company. Both began their quarry operations just outside of Pacific, Missouri in the mid-20th century. When they began operations, they transported gravel to St. Louis by train line. Today, gravel and sand are hauled by truck. Ryan Winter, the Vice President of Winter Brothers, remembers his grandfather telling the story of when the company changed transportation modalities "In the 1930s, aggregate was mined at the Pacific Palisades depot and hauled into south St. Louis by locomotive. By the 1940s, both roadbeds and trucks were engineered to withstand hauling heavy loads. It was then that my grandfather argued in favor of the trains raising the government's limits on their rates. He reasoned that he could reach his deposits by road, undercutting the railways' cost" (Winter 2020).

1.3 *Meramec rock as aggregate in concrete*

The hardness, shape and porosity of an aggregate determines its efficacy in concrete. Meramec gravel is dense, hard, and incredibly durable. Throughout the region concrete with Meramec aggregate is extolled as mythically strong. Dake states "Where structures are subjected to severe tests, care should be taken to use gravels only, the pebbles of which are themselves strong…In most well-worn creek sands and gravels, there is usually little need to examine for chemical decay, especially in the Ozark region where flint gravel is the rule" (Dake 1918, p. 61).

The shape of gravel helps to determine whether its matrix will pack densely into the concrete mix. Rounded gravels pack less densely than angled or pointed gravels, where individual pieces rotate to fit into spaces of adjacent elements. Grading the gravel by size can help to fill voids when using rounded gravels. Typically cement adheres to roughened surfaces better than smooth. Dake states "All other factors being equal, an aggregate the pebbles of which have roughened surfaces will produce the strongest concrete…cement will adhere more readily to a rough that to a smooth surface." Dake goes on to say "Results of tests made by the Bureau of Standards at Washington, and conducted at the request of the Missouri Bureau of Geology and Mines, seem to show that flint gravels are satisfactory for concrete work…These smooth flint gravels are being used extensively in St. Louis, apparently with good results, and engineers have expressed it as their opinion that by proper grading first class concrete can be made of this gravel" (Dake 1918, p. 60–61).

Analysis by Kadri Kasapoglu in his 1969 thesis points out that in Meramec gravel "more angular chert particles have a glossy surface texture whereas the surface texture of rounded chert particles are rougher" (Kasapoglu, 1969, p. 54), meaning the efficacies of shape and surface character cancel each other out.

In order for Meramec gravel to be effective in concrete, it must also be free of deleterious material. Positively, the Meramec River does not pass through coal bands, so there is no contamination by lignite in the fines. Lignite floats to the concrete surface and drags on trowels during finishing. Without contamination, the resulting concrete gives a smooth and creamy surface for flatwork. Ryan Winter states "The Meramec runs a relatively short distance and does not cross any coal seams. So, unlike the Mississippi and Missouri rivers, sand from the Meramec does not contain lignite. Lignite is deleterious, a soft friable particle that rises to the surface. It catches finishers' trowels and weathers away – degrading surface smoothness" (Winter 2020).

The works of Dake and Kasapoglu represent the only scholarly reporting on Meramec gravel. Based on the author's survey of publications, nothing has been written since. Knowledge of the material instead resides in the oral narratives of business owners like Ryan Winters, and by surveying and inspecting examples of projects that use Meramec gravel as aggregate. Historically, and even today, one would never know based on its use in the region that Meramec gravel is considered a deleterious material when used in concrete.

2 PROBLEMATIC BEHAVIOR OF MERAMEC ROCK

2.1 *Silica Alkali reactivity*

Meramec gravel is chert. Chert contains noncrystalline silica that is reactive with cement. When hydrated, a gel forms around the aggregate. When the gel dries it leaves behind air pockets. Water infiltration in conjunction with freeze thaw cycles can exert pressure to cause the concrete to pop and crack. This is interchangeably called silica alkali reactivity (SAR) or alkali silica reactivity (ASR).

Patrick Mulvaney, Unit Chief, Missouri Geological Survey, explains “Chert and quartz are the dominant constituents of Meramec River gravel, and this is typical for Ozark stream gravels. Chert is considered to be a deleterious constituent for concrete for reason of the Silica-Alkali-Reaction (SAR)…The vendors of concrete like to tout the hardness of the chert aggregate they use in their concrete. They also like chert because it is cheaper than the quality limestone aggregate that is used in premium concrete [as specified by the Missouri Department of Transportation]” (Mulvaney 2020).

The U.S. Department of Transportation thus explains the history of the reactivity: “Problems due to ASR were first identified in the State of California in the 1930s and reported by Thomas Stanton of the California State Division of Highways in 1940. Stanton’s studies demonstrated that the expansion of mortar bars was influenced by the alkali content of the cement, the type and amount of the reactive silica in the aggregate, the availability of moisture, and temperature. He further showed that expansion…could be reduced by pozzolans, thus setting the groundwork for preventive measures” (Thomas et al. 2013, p. 2).

C.L. Dake’s book from 1918 does not mention SAR because the phenomenon was not discovered until 1940. As a result, C.L. Dake presents Meramec gravel as having the potential to be an important and appropriate constituent for concrete. The other major scholarly work on Meramec rock, Kasapoglu’s thesis, only tangentially mentions this reactivity. Even today information about the gravel’s reactivity is not widely revealed by local St. Louis’s suppliers and seems relatively unknown to tradesmen and architectural practitioners. Partially this may be because a byproduct of the industrial revolution is widely used as an additive to concrete, and by chance, this byproduct offsets SAR.

2.2 *Pozzolans: Fly ash*

A few years prior to the discovery of the reactivity of chert, research was being done on the effects of adding fly ash to concrete. Fly ash was a deleterious byproduct of coal burning plants – the sheer mass of ash produced by the plants and associated environmental concerns made it a priority to find a way to use the material. With proximity to coal deposits and a river system that allowed easy transportation, St. Louis and other cities in the Mississippi river valley built large numbers of coal burning plants.

“With the advent of the development of the pulverized fuel boilers in World War II and growing environmental concerns, fly ash started to be produced in the mid-1940s in adequate quantities to develop utilization markets. In the mid-1930s, Professor R.E. Davis of California performed and reported on research done on fly ash and fly ash use in concrete” (Manz & Pflughoeft-Hassett2005).

The benefits of using fly ash included improvement to workability, decreased need for water, and decreases in heat output during hydration (US DoT, 2017). In 1940, Thomas Stanton, from the California State Division of Highways, published that using pozzolans in concrete diminished alkali silica reactivity with deleterious aggregate such as chert. “The potential for using pozzolans to control damaging ASR was demonstrated by Stanton (1940) in his landmark paper that first revealed the phenomenon of alkali-silica reaction to the concrete community…Ten years after Stanton’s (1940) discovery of ASR the potential for using fly ash and slag for controlling expansion was first documented, and it is now widely accepted that supplementary cementing materials are an effective means for controlling ASR expansion provided they are used at a sufficient level of replacement” (Thomas et al. 2013, p. 4–5). Thus, a prevalent byproduct of the industrial revolution was able to offset the negative effects of a gravel which was equally prevalent and deleterious. The unlikely case of two wrongs making a right, or at least an acceptable situation, has allowed Winter Bros. and Simpson Materials to continue supplying Meramec gravel for concrete aggregate needs across the region.

3 MERAMEC ROCK AS AGGREGATE IN BUILDINGS AND INFRASTRUCTURE IN ST. LOUIS

Historically, St. Louis is a city of stone and brick. Buildings were constructed from limestone quarried from the Ozark plateau and red granite outcrops ninety miles to the south. Plentiful clay deposits provided brick. The city was also built with river gravel hauled from the Meramec River basin. Despite its prevalence – the author found no scholarly work cataloging where Meramec gravel was used in the St. Louis built environment, or any published information on the expertise by which it was employed. As such the following text attempts to provide a framework for further research. St. Louis is literally paved in this aggregate, but its history is driven by myth and narrative with very little data as substantiation. The remainder of this paper seeks to initiate a catalog of applications across infrastructure, and buildings – from exemplary to defective. Further research (beyond the scope of this short paper) will provide research on pouring methods and mix design historically used in these applications.

3.1 *Infrastructure*

Infrastructure in St. Louis such as curbs, sidewalks, bridge abutments, foundations, and viaducts utilize Meramec gravel as aggregate. In the oldest parts of the city, one can still observe red granite cobblestone or brick streets, with red granite curbs. In the late 19th century through the turn of the 20th century, pavement contractors began laying granitoid sidewalks made

Figures 2(left) and 3(right). Delmar Boulevard Walk of Fame, detail photo of surface with exposed aggregate. (photo credit: author).

from concrete with red granite chips. In the following decades, the rapid construction of neighborhoods required investment in large scale sidewalk installation. Contractors shifted to using more economical Meramec aggregate. Throughout the city sidewalks were seeded with fine grain Meramec aggregate to create a caramel brown colored surface. In some cases, these sidewalks are sealed yearly to maintain the chert's shiny luster.

The Delmar Walk of Fame in University City provides an example of Meramec aggregate ornamentally used in sidewalk construction. University City is a municipality adjacent to the City of St. Louis. In the 1970s, urban flight affected the municipality's main commercial street, Delmar Boulevard. The streetscape became desolate and the sidewalk fell into disrepair. The proprietor of one of the few remaining enterprises, Blueberry Hill, hatched a plan to repave the sidewalks. Joe Edwards proposed the idea of a walk of fame honoring local musicians, sportsmen, writers, and scientists who became nationally and internationally recognized. Each year the bronze stars for a few more inductees were installed, meaning the sidewalk pavement around the stars had to be replaced. What is now widely considered as a significant tourist attraction in St. Louis began as a guerrilla style urban redevelopment project (Figures 2 and 3).

In the 1930s and 1940s, construction of widened and streamlined roads intersected train lines, with both infrastructures negotiating changes in elevation across St. Louis's rolling hills through the use of bridges and viaducts. Reinforced concrete served as the construction material of choice – many of the automobile bridges have since been replaced, but several train viaducts and bridge abutments of note remain. "From 1929 through 1955, the MacArthur Bridge carried United States Route 66…Today the active MacArthur Bridge is the 17th busiest railroad bridge in the United States" (Preservation Research Office 2012).

Figures 4(top) and 5(bottom). MacArthur Bridge guardrail and Chippewa street underpass.

The MacArthur Bridge Train Trestle began construction in 1909. Designed by Boller & Hodge, this steel truss bridge contained a second deck for vehicular traffic. The guard rail adjacent to the vehicle ramps is composed of precast reinforced panels installed between cast in place posts and capped with a precast handrail. The unmistakable shiny brown aggregate is Meramec gravel. The Roman lattice pattern is in keeping with the bridge's truss design. It is difficult to tell if surfaces were bush hammered, or whether aging and highway salt have removed the smooth surface of the concrete. Visible variation in aggregate size along the surface shows that vibration techniques resulted in separated aggregate in the mix, with areas of compactly packed aggregate bonded with little or no cement. (Figure 4)

Two train viaducts are better preserved. The Gravois avenue overpass was constructed in 1937, while the Chippewa street underpass was completed in 1940. Both provide uninterrupted train access across major roads for the train line that travels from St. Louis through Pacific, Missouri to points further west. Precast balustrades with narrow arched openings are set between cast-in-place supports with recessed panels. A precast cap acts as handrail. The arched openings are similar to many Works Progress Era projects across the country. In both viaducts, the ratio between cement and aggregate is far more typical than seen in the MacArthur Bridge guard rail. The treatment with a chemical resist means that the aggregate is apparent on the surface, its brown shiny color denoting it as Meramec rock (Figure 5).

Beyond sidewalks and viaducts, downtown St. Louis also has a historic reinforced concrete example of commercial infrastructure which serves the

Figure 6(left) and 7(right). Pet Milk building, and exposed limestone aggregate. (photo credit: author).

Figure 8. Pet Milk Building concrete surface imprinted with board formwork. (photo credit: author).

rail lines. Elevator "D" grain silo was built in 1953. As Maria Altman of St. Louis Public Radio reports, "The 88 bins housed within [the silo] can hold 2.4 million bushels of grain" (Altman 2014). Close inspection of the surface reveals the unmistakable evidence of Meramec rock used both as aggregate and as sand.

3.2 *Architecture: Meramec gravel as aggregate in the mix*

The use of Meramec gravel in infrastructure throughout St. Louis is easily seen through the brownish cast of concrete surfaces on bridges and abutments. The use of Meramec gravel in architecture is less obvious. In a city of brick and stone buildings, there is not as rich a history of buildings with unclad reinforced concrete facades. However close inspection of most concrete buildings reveals at least small aggregate and sand that has the unmistakable brown cast of Meramec gravel.

Arguably the most widely regarded example of exposed concrete in St. Louis is the Pet Milk Building (now Pointe 400) located adjacent to the interstate exchange that replaced Highway 66's route over the MacArthur Bridge mentioned earlier in this paper. This iconic brutalist building was designed by A.L. Aydelott and completed in 1969. Aydelott's works included the US Embassy Chancery in Manila, Sears and Roebuck Stores, and many buildings in Memphis (Aydelott Archive 2020).

In the 1969 Architectural Record article *A powerful silhouette for a high-speed environment*, the description states "Its location is a prestigious one adjoining the still-developing river-front park surrounding Saarinen's Jefferson Memorial Arch... To create the desired corporate image in this high-speed, "landmark" environment, A. L. Aydelott & Associates, have articulated the building's elements into a bold, expressive statement" (Architectural Record 1969, p. 163) (Figures 6–8).

The overall massing of the building in conjunction with the sculptural use of precast sunscreens enliven the façade. However, it is the careful detailing that particularly enriches the design.

"Two textures of concrete appear throughout. The rougher concrete was poured in place and retains the imprint of its wooden form; the smoother, pre-formed concrete panels offering a slightly contrasting color are used as wall surfaces and for intricate sunscreens on the east and west facades…The architect, Alfred Aydelott, featured other details in the concrete. The steel reinforcing rods used in strengthening the walls were cut off on the exterior and capped with stainless steel disks. Other surfaces of pre-stressed concrete panels with exposed aggregate are smoother and a slightly lighter color" (Toft & Sone 2004: 1).

The stainless-steel discs sparkle in the sunlight. The surface of the precast spandrel panels is exposed white and tan limestone set in Portland cement. What is deemed the "rougher concrete" presents a highly refined and crisp imprint of the wood formwork with a slight brownish cast. The detailing resembles the negative of a photograph. Inspection of the surface shows granules of Meramec chert embedded in cement. The intact surface shows no sign of damage from alkali silica reactivity or weathering.

A second building is the St. Louis Ethical Society Meeting House. Locally renowned architect Harris Armstrong designed the building, which was completed in 1964. In 1935, Armstrong introduced the International Style to St. Louis after working for Raymond Hood in New York. Several of his projects were published in Architectural Review and Architectural Record. In the second half of his career Armstrong became interested in the later work of Frank Lloyd Wright, and his projects increasingly expressed materiality.

"His palette of building materials expanded to include natural building materials such as brick, stone, and wood. His formal interests developed rapidly in several directions; some of his works paid homage to the explorations of Frank Lloyd Wright; his personal design methodology pushed some of his more inventive projects beyond his contemporaries" (Raimist 2020).

Figures 9, 10, and 11(clockwise). Ethical Society Meeting Hall, concrete columns, and concrete surface. (photo credit: author).

The Ethical Society Meeting House's expressive design includes a wood structure supporting the copper clad roof, wrapped in a reinforced concrete exterior structure, with paneled glass and precast concrete cladding. Close inspection of the concrete structure reveals finely scaled brown Meramec gravel as aggregate for the concrete of the columns, ledges, and roof structure. The concrete roof beams, which have lost their smooth surface to erosion reveal the Meramec gravel in particular. Across the entire structure the careful crisp detailing remains intact fifty-six years after completion. Contrasting with the brown cast of the structure, the precast concrete panels are seeded with pink and red marble chips cast in a cement and sand finish, producing an overall pinkish hue (Figures 9–11).

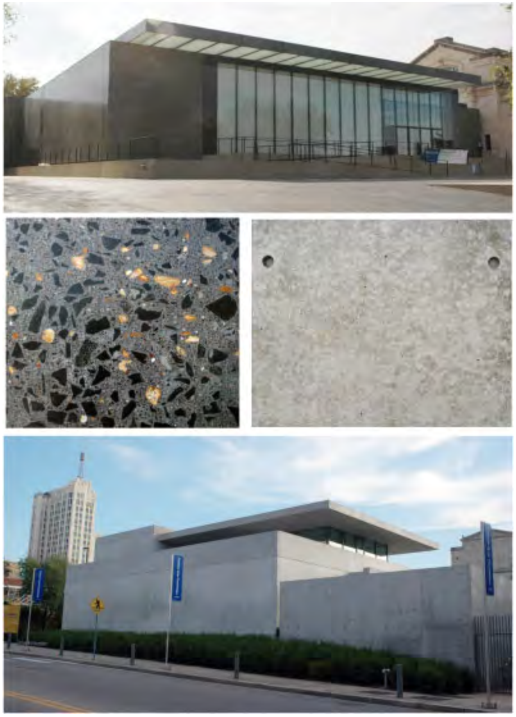
3.3 *Architecture: Exposed aggregate*

In the 1960s and 1970s, St. Louis's architects designed a range of buildings constructed with exposed aggregate panels. Two of the most significant projects were Mansion House and Council Plaza. Both were designed by the local architecture firm Schwarz & Van Hoefen. Both buildings represented St. Louis embracing the modern movement and the idea of the mega structure which incorporated all the needs of modern living within a single development. The use of exposed white limestone aggregate in precast panels in conjunction with ribbon windows portrayed a sleek modern style in keeping with the stated project ideals. Three additional examples are: the Kimberly Building, 2510 S Brentwood Boulevard (1965); the Ruder Building, 11710 Administration Drive (1971); and 620 Market Street (1978). The white, tan, and grey marble aggregate in the Kimberly building is cast into white cement to create panels installed as spandrels below and above windows. The Ruder Building is composed of a series of channel shaped precast panels elegantly detailed as a second story hovering above columns infilled with a glass curtain wall. The aggregate is white and tan quartz set in white cement. Finally, the panels of 620 Market Street are granite chips set into a tan cement featuring Meramec sand – the tiny brown chert particles reveal the sand's origins. Detailing shows the thinness of the precast panels and their connection to the steel superstructure. All of these projects favored using more precious stone as exposed aggregate.

Figures 12, 13, 14, and 15 (clockwise). Above: 1004 Chouteau Ave., detail photograph with aggregate and epoxy coating. Below: Sheraton Hotel, Westport Plaza, with detail photograph showing prevalent caulk detail. (photo credit: author).

The author located two additional examples that specifically feature exposed Meramec gravel. Meramec gravel was viewed as a cheaper and less desirable material than limestone, granite, and marble aggregates. The two examples are also less desirable in their design character in comparison with the other projects, in particular exhibiting poor detailing. 1004 Chouteau Avenue, built in 1979, is a windowless construction clad with precast C shaped units. The units feature Meramec gravel aggregate as their only ornament. At some point, either to lighten the appearance of the building, or to decrease degradation, the entire building was sealed in epoxy paint. One small area did not received paint and reveals the original surface, (Figures 12, 13).

A second building is a Sheraton Hotel constructed as part of Westport Plaza in 1973 by the developer Thomas J. White. While exhibiting reference to Brutalism, the building is far less bold and expressive than the Pet Milk Building discussed earlier in this paper. Precast panels feature Meramec gravel exposed aggregate. The caramel brown color coordinates well with



Figures 16, 17 (top, center left). St. Louis Art Museum addition, detail photograph of precast panel. Figures 18, 19 (center right, bottom). Pulitzer Arts Foundation, detail photograph of poured in place concrete. (photo credit: author).

the bronze of the curtain wall. An unfortunate attempt to seal the building using grey caulk clashes with the building's material palette and emphasizes the lack of care in detailing the expansion joints between panels. At the entry of the hotel the exposed aggregate has been sealed under a coat of epoxy paint. (Figures 14, 15)

Interestingly, investigation of the carefully detailed buildings, such as the Pet Milk Building and the Ethical Society Meeting House, did not exhibit degradation due to Silica-Alkali Reactivity. Perhaps this is because these buildings were constructed after the standard incorporation of fly ash as pozzolan or because vibrating techniques and mix design prevented the reaction.

3.4 *Continuing the legacy: Award winning contemporary buildings*

Two contemporary projects of note illustrate the continued employment of Meramec gravel in buildings throughout the St. Louis region: as aggregate in the mix design for the Pulitzer Arts Foundation by Tadao Ando (2001), and as exposed aggregate in precast panels for David Chipperfield's St. Louis Art Museum addition (2013). In both cases, but for different reasons, Meramec gravel was the perfect choice for the projects, (Figures 16–19).

In 2013, the world renowned architect David Chipperfield completed an addition to the St. Louis Art Museum. The façade features polished tilt up concrete panels. From afar they appear dark grey or black, however upon closer inspection the aggregate is a mix of black trap rock and Meramec chert, reflecting the local sourcing of materials. The aggregate was cast in a dark grey epoxy cement, and the panels were polished using a method similar to finishing terrazzo. Julie Bauer, former Project Architect for Chipperfield and Associates, explains "We used Meramec gravel for the exterior tilt-up panels. It worked well, because we were looking for an aggregate that picked up the color of the existing building. Meramec was hard enough to be cut, grinded and polished…The black aggregate is Trap rock. I don't remember how exactly we got to Meramec, we went through a very extensive mock-up production period, first in DD and more specified in CD... I think it quickly became a candidate, because it is such a common gravel product in St. Louis, every sidewalk is made of it" (Bauer 2020).

Pritzker prize winner Tadao Ando has won acclaim for the high quality of his concrete. He requires exceptional attention to detail but maintains that there is nothing special about the concrete he uses. Indeed, in St. Louis the concrete for the Pulitzer Arts Foundation used Meramec gravel, as it was local and prevalent. Its hardness and tendency not to absorb water helped in regulating the consistency of the concrete mix design. Steve Morby, former project superintendent, explains "To get the smoothness and fineness of detail that Ando required, the concrete needed to be tight enough to mimic the form surface we were pouring against…Getting some re-occurrence of amounts of bleed water, and a consistent understanding of how much water was actually in the mix was the main reason we were looking to change aggregates [from limestone]. There is a rock here in St. Louis that is amazing for its strength, and for its lack of water absorption, Meramec rock…in St. Louis, you can pretty much drive anywhere around on the interstates and you find a brown cast to the worn concrete, that's the Meramec sand and gravel that we used in the mix. It makes for extremely strong concrete" (Morby 2013).

4 CONCLUSION

Meramec Gravel is a prevalent and historically important construction material in the St. Louis region for both architecture and infrastructure. However, the chemical makeup of chert results in an inherent weakness as a component in concrete due to its propensity for alkali silica chemical reactivity. To some extent this reaction can be tempered through the addition of pozzolans, such as fly ash. Despite its problems, chert continues to fundamentally define the concrete of St. Louis, both historically and through its selection by world renown architects as aggregate for contemporary projects in the region. As a result, the warm caramel cast of the concrete is un-mistakeable and defines the region. The purpose of this paper is to begin to establish a framework by which this prevalent material can better be studied from a scholarly perspective.

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History of Construction Cultures – Mascarenhas-Mateus & Paula Pires (eds)

The Northern Lock, The Netherlands: At the frontier of 1920s concrete technology

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ABSTRACT: The Northern Lock (‘Noordersluis’, 1924–1928) was one of the world’s largest pre-World War II infrastructural works. It was part of a series of enhancements of the North Sea Canal, connecting Amsterdam to the sea. It was designed by a team of engineers led by Johannes Ringers, including J.P. Josephus Jitta, C. Tellegen, F.E. Mulder and B. Peiser. The challenges faced were at the frontier of 1920s concrete technology: development of concrete resistant to water penetration and cements with low heat development and good seawater resistance as Portland cement was not durable in marine environments. The latter were found in blast furnace slag cements and trass additions. Usage of blast furnace slag cement was novel for the Netherlands and a violation of contemporary regulations. Its bold introduction by Ringers and colleagues is a lasting legacy of the Northern Lock, resulting in the widespread use of ground granulated blast furnace slag cements with high slag contents (CEM III/A with >50%, CEM III/B with ca. 70–72% slag) for major infrastructural works in the Netherlands, with evident durability and sustainability gains.

1 INTRODUCTION

The Netherlands has a long history of hydraulic works with territory partially located under sea level. Furthermore, the Dutch economy was and is strongly dependent on shipping. At the beginning of the 20th century, the latter required guaranteeing access to ever rising sizes of seafaring vessels to the Port of Amsterdam. In 1909, a government committee had been established “…because the question has again been raised whether Dutch interests in general and those of Amsterdam in particular would be sufficiently guaranteed in the future by a canal that allowed ships of 220 m length, 24 m width and ca. 24 dm depth to pass from and to the sea. Especially the fact that the works on the Panama Canal have been ongoing since 1906 that, after completion, -which meanwhile occurred in 1914, would allow passage of ships of 305 × 33½ m and 126½ dm depth. Also, improvements to the Suez Canal were meanwhile started…”’ (Gelinck 1924). On January 2, 1917, a law was announced by the Dutch central government to enable the improvement and enlargement of the North Sea canal, which connected Amsterdam to the North Sea.

Part of this improvement was the construction of the new Northern Lock (Dutch: Noordersluis) at IJmuiden (Figure 1). At the time, this project took several records, such as one of the largest infrastructural works constructed in reinforced concrete (Figure 2) in the Netherlands prior to the Second World War, and larger than the locks on the Panama Canal (1914) and the Kiel Canal (enlarged 1914). The lock was designed for

Figure 1. Overview of the Northern Lock, 1950s-1960s (Image courtesy Beeldbank Rijkswaterstaat).

Figure 2. Drawing to illustrate the sheer size of the lock by comparing it to the H.P. Berlage designed stock exchange in Amsterdam (anonymous 1929).

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ships of up to 100,000 tons at a time when the biggest ship, the ocean liner Leviathan, was 56,000 tons large (Visser 1927).

The lock was constructed between 1922 and 1924, and officially opened in 1930. It was designed by a team of engineers led by Johannes Ringers (1885–1965). Ringers would later become Director-General of Rijkswaterstaat (the Dutch government infrastructure agency), government commissioner for post-war reconstruction (an appointment made one week after the German occupation of the Netherlands in 1940), a resistance member, and neutral Minister of Reconstruction after the Second World War (Van der Ham 1998, Pollmann 2006a,b). His team included the engineers J.P. Josephus Jitta, C. Tellegen, F.E. Mulder and B. Peiser.

In preparation for the works, Ringers and several others made a study trip to locks being constructed in France and Germany (Van Panhuys et al. 1921). The construction was accompanied by elaborate applied scientific research. The engineers published their results and evaluations in the Dutch national engineering magazine *De Ingenieur* (Josephus Jitta 1928; Ringers 1924; Ringers & Peiser 1925; Tellegen et al. 1924). Furthermore, it earned Ringers the degree of *doctor honoris causa* at Delft University of Technology in 1930. From the beginning onwards, the construction works attracted attention from the Netherlands and abroad (e.g. Kittel 1925); a party of German professors visited the construction site in July 1924 (anonymous 1924a).

At the time of construction, concrete technology was changing. The previous, mostly empirical approach combined with the secrecy of patents and lack of standardization, was steadily under replacement by a more professional and standardized approach towards concrete technology (Heinemann 2013). For the Northern Lock, fundamental durability issues of concrete also had to be answered. The construction of the Northern Lock was thus more than an engineering challenge, it addressed the entire construction chain, from quality control over participants, guaranteeing durable structures and upscaling construction sites.

One aspect was the increasing need for sophistication in mix design, as “the common 1 : 2 : 3 mix for reinforced concrete was not considered waterproof in the Netherlands” (Bienfait 1932). But what alternatives? More cement per cubic meter of concrete will result in higher heat development and consequently more shrinkage cracks, a relevant aspect considering the scale of the concrete pieces. Additionally, resistance to seawater was clearly an important issue. Several studies were initiated by the construction team and are duly related below.

These large-scale investigations, partly onsite, initiated a history of research. Over the years, repeated inspections and material characterizations have been performed by contractors, consultancy firms and the Netherlands Organization for Applied Scientific Research TNO, in particular in the 1980s and 1990s. The total set of results has, however, never been evaluated from the original perspective: which concrete mixture is most suitable and durable?

In retrospective, there is another reason the Northern Lock is a very interesting case. Dutch construction practice differs from many countries through the large-scale use of ground granulated blast furnace slag cement (CEM III/A with > 50% slag or CEM III/B) for main infrastructures because of the superior performance with respect to durability (e.g. Polder et al. 2014). The Northern Lock was the first major structure made with a kind of cement with high slag content in the Netherlands and, as already noted by Heerding (1971), provides the foundations for this important choice.

In this paper, the results of material research carried out on samples from the lock taken over the years are presented and complimented with literature and archival studies in order to illustrate the pivotal role of the Northern Lock within the progress of concrete technology in the Netherlands.

2 CONCRETE MIX INVESTIGATIONS

2.1 *Laboratory tests*

When the planning of the Northern Lock commenced, the composition of a concrete which would be durable in a marine environment was still widely investigated (Heinemann 2013). Dedicated research whilst considering local constituents was required for the lock.

A first binder study was performed by professor Georg Rüth (1880–1945) affiliated to both the German cement company Dyckerhoff & Widmann A.G. in Biebrich am Rhein (near Wiesbaden) and the Technical University of Darmstadt in 1921–1922. Investigations by professor Rüth concerned the relationship between concrete mix and waterproofness, the possible use of (fine grained) dune sands (interesting from an economical point of view) and trass; the latter was expected to improve resistance against seawater. Mixtures were based on ordinary Portland cement, obtained from the German factory Dyckerhoff & Söhne and British producer Tilbury; other aspects investigated were heat of hydration, compressive, tensile and shear strength, water penetration and shrinkage (Bienfait 1932).

2.2 *Onsite concrete testing*

Subsequently, studies were performed by the construction team in IJmuiden on the hardening of cement, cement-sand and cement-trass-sand mixtures in seawater between 1926 and 1928. As announced by Ringers in 1924: “The water that will enter the lock will be brackish, meaning one might be afraid of seawater attacking the concrete. This might be countered considerably by using a ‘rich’ concrete mix, i.e. a high density and adding trass to the cement. In periods with

Table 1. Concrete mix specifications given by Bienfait (1932) recalculated to current units ($\mathrm{kg\,m^{-3}}$) assuming 1 l cement = 1.25 kg (according to the original specification), a water/cement ratio of 0.6, air content of 2 vol.%.

	Mix		Cement type		Aggregate kg $\mathrm{m^{-3}}$	Water		Vol. Mass		Compressive strength N $\mathrm{mm^{-2}}$		
Use	Portland	Portland-slag	Blast furnace. Slag	Trass		Fine	Coarse			7 days	28 days	365 days
Piles	2	307–315	–	–	61–62	732–752	927–952	184–189	22238–2247	6.7–10.7	21.2–28.8	35.7–44.7
Piles	3	398	–	–	–	574	1006	239	2267	25.9	31.5–37–9	46.2–47.1
Piles	3	–	398	–	–	574	1006	239	2267	22.0–25.9	32.2–46.4	46.2–48.2
Piles	4	385	–	–	–	745	922	230	2280	17.7–29.9	29.4–41.7	39.9–51.1
Piles	5	330	–	–	59	734	908	198	2230	10.0–14.2	16.2–24.8	25.8–35.4
Casing	2a	265	–	–	50	849	977	159	2299	4.1–13.1	9.0–27.1	27.3–34.8
Casing	2b	–	–	305		870	988	183	2345	10.7	17.7	27.3
Casing	2c	278	–	–	43	794	1018	167	2299	9.9	14.5	28.7
Wall Lock chamber	3b,d	249	–	–	45	823	1055	149	2321	3.1–12.3	5.5–18.1	19.9–29.7
Wall Lock chamber	3c	278	–	–	43	784	1018	167	2299	9.8–11.3	16.8–19.7	26.3–36.6
Wall Lock chamber	3g,I	273	–	–	49	846	961	164	2293	7.6–14.8	12.6–21.2	18.9–33.6
Wal Lock chamber	3c	–	–	274		847	1086	164	2370	2.9–6.1	11.3–15.8	20.9–26.3
Floors	4a	298	–	–	56	635	1096	179	2363	6.2	15.3	24.9
Floors	4b	–	–	299	–	820	1052	179	2350	3.4–10.5	15.7–17.4	19.9–29.1
Floors	4c	273	–	–	49	846	961	164	2293	8.7–12.3	10.2–18.1	21.4–31.8
Upper Part lock Chamber	5a	–	–	305	–	870	988	183	2345	3.6–6.5	7.1–10.5	12.6–21.1

frost at night and the cold season in general, trass, however, slows down the hardening to such an extent that this addition is not without doubt. The large dimensions of the structures would, because of the amount of shrinkage, demand a leaner composition. It was decided to investigate the demands on cement to be safely used in seawater when possible without trass. The construction site is well suited [for this investigation], as seawater is available there . . . The ongoing tests an imitation of a similar test performed in Atlantic City (America) and reported in the second part of Technical Paper of the Bureau of Standards No. 12 Action of the Salts in Alkali waters and Seawater on cements 1913" (Ringers 1924).

Studies of concrete hardening in seawater involved various kinds of cements, including ordinary Portland cement, blast furnace slag cement and mixtures of slag cement (i.e. cement with a low slag content, probably comparable to current CEM II/A-S or B-S) and Portland clinker (Table 1). Blast furnace slag gave lower strengths but did perform well with respect to hardening in seawater (Bienfait 1932). To some concrete mixtures, Fluresit and Tutorol were added in a ratio of 1:20 relative to the water (Bienfait 1932). Fluresit, described as a silicate solution (i.e. water glass), was probably a product of Fluresit Industrie G.m.b.H. in Hanau am Main / Leipzig (cf. Grün 1926). Tutorol was a kind of fluate produced by Dr. Haller und Ko. of Berlin (Schmidt 1925, Niemeyer & Sautter 1941). Fluates (or fluosilicates) were often used in this period as surface treatment on all kinds of porous stony materials and also mixed into cement-based products (cf. Nijland & Quist 2018). Both showed almost no effect (Bienfait 1932).

The testing of the strength of concrete mixtures with various cements, with or without trass, took place simultaneously in IJmuiden and at the company Proefstation voor Bouwmaterialen Koning & Bienfait in Amsterdam. To determine the compressive strengths of concrete mixtures actually used, the government's Department van Waterstaat (predecessor of the current Rijkswaterstaat) had bought a brand new 500 tons compressive strength bench from the company A.J. Amsler in Schaffhausen, Germany. This was installed on the construction site. After completion of the lock in 1928, it was obtained by Proefstation voor Bouwmaterialen Koning & Bienfait, which had supervised the tests (Bienfait 1932). Tests were performed on cubes of 30 × 30 × 30 cm cut from the cast concrete. About 2,300 cubes in total were tested. On request of Ringers, all results were published after completion of the project by Jacques Louis Bienfait. The booklet, entitled *Investigation and testing of the most important materials used in construction the new lock in IJmuiden, 1921–1929* (Bienfait 1932) went on sale for two Dutch guilders for everyone interested.

Based on the concrete mixes studied (Table 1), mixtures were produced in practice, often with slight alterations in the amounts of different materials. Variations in cement content, the moisture content of the sand and grain size of the coarse aggregate resulted inevitably in a considerable spread in properties, which was already realized by the construction team (Ringers & Peiser 1925). The concrete was also made with cements from various producers (Bienfait 1932), inevitable given the amount of concrete required, 200,000 tons, for which 60,000 m^3 cement was needed. At one moment: "Used were the following kinds of cement: 342 tons Mattesholm cement, 45 Wicking cement, 5 tons Grimberg cement and 8 tons blast furnace slag cement (Rombach)" (Tellegen et al. 1924). Listed are a Swedish cement, a German cement produced by Wicking'sche Portland-cement und Wasserkalkwerke A.G., a producer of growing importance in the 1910s and 1920s, a cement probably originating from the factory Grimberg & Rosenstein in Ennigerloh (Beckum), Germany, in which Wicking had held a majority of shares since 1917 and closed when the latter obtained all the shares in 1926 (cf. Cramer 2009) and a blast furnace slag cement from Portlandzementwerk A.G., Rombach in the Lorraine (cf. Passow 1908). For the walls of the lock chamber, blast furnace cement called Weser, produced at the factory of the iron works Norddeutsche Hütte in Bremen, was used. Here, production of blast furnace slag cement with its own Portland clinker had been established in 1912 (Holcim Deutschland AG 2012).

3 THE CHOICE OF BLAST FURNACE SLAG CEMENT

The Dutch Reinforced Concrete Regulations from 1918 (GVB 1918) were explicit: blast furnace slag cement was prohibited. In Prussia, it was already considered as equal to Portland cement in 1917 (Heinemann 2013). For a different major lock in Geestemünde, Germany, blast furnace slag was applied due to its better resistance to seawater (Heerding 1971). The experiments in IJmuiden were similarly positive. Ringers briskly dismissed the ban in the GBV 1918 at a meeting of the Civil and Hydraulic Engineering Section of the Royal Institute of Engineers (KIVI): "…that we will not take much notice of the ban on the use of this type of cement contained in the Concrete Regulations. This ban was introduced when we did not yet know about it, and we have carried out numerous tests with it since then" (anonymous 1924b). These tests were positive: "that for a first batch of blast furnace cement the results were as good as those of normal cement" (Tellegen et al. 1924). The general suspicions about blast furnace cement become clear in a remark by C.J. Tellegen in the same meeting: "But there is a lot of difference between blast furnace cements and a lot of confusion with iron and ore cement. In Belgium, hydrated lime and slag sand are mixed together, and cheaters can sell that mixture as Portland cement because the figures in the regulations are too low… In Germany, there is a consortium of blast furnace cement works, which has its own study and testing station in Düsseldorf. That syndicate has been fighting for years against Portland cement manufacturers for a place in the sun, and the use of cements from these plants is now permitted on an equal footing with Portland cements, according to the Prussian Government's decision. However, when using a blast furnace cement, care will have to be taken to actually obtain a product for which this equivalence indeed exists" (anonymous 1924b).

Concrete from the lock has repeatedly been investigated ever since its construction, including laboratory investigations of cores. In terms of compressive strength, the results reported a considerable increase after one year. The OPC + trass mixture for the walls and lock chamber 33.0 ($n = 3$) and 49.3 N mm^{-2} ($n = 11$) at ca. 55 (Wiebenga 1981) and 67 years (Heijen & Lurkin-Van Antwerpen 1995), respectively, compared to 25.3 N mm^{-2} ($n = 22$), whereas the OPC + trass mixture for the floors showed 26.0 N mm^{-2} ($n = 4$) after one year and 49.4 ($n = 1$) in 1981 and 58.2 N mm^{-2} ($n = 2$) in 1995. The blast furnace slag cement mix for the same purpose gave 25.0 N mm^{-2} ($n = 2$) at 1 year and 51.7 N mm^{-2} ($n = 6$) in 1995, whereas the blast furnace slag cement mix for the upper part of the lock chamber gave a comparable 16.7 ($n = 3$) and 43.2 N mm^{-2} ($n = 2$) at 1 year and in 1995, respectively.

Another relevant observation concerns the relationship between the occurrence of alkali-silica reaction (ASR) and the concrete mixtures used. In the early 1980s, ASR was diagnosed in structures from the Netherlands; in the1990s, it was also diagnosed in concrete from the Northern Lock (Zuidgeest 1993, De Haas 1993). It appeared that whilst deleterious ASR is present in the mixtures with OPC, it is absent in those with blast furnace slag cement (Heijnen & Lurkin-Van Antwerpen 1995; Siemes 1995; Siemes & Larbi 1996). Besides all the other reasons for differences in performance, this should consider how slags from the 1920s were generally considerably less amorphous than modern versions (Figure 3).

Typical of working with building innovations, the unexpected consequences of the use of blast furnace slag cement did occur. As the concrete hardened slower, a desired effect to control heat development and avoid cracking, it also meant that it could not carry its own weight as quickly as concrete made with Portland cement. This required empirical research into designing strong enough formwork to maintain the required concrete pouring pace (Peiser 1927).

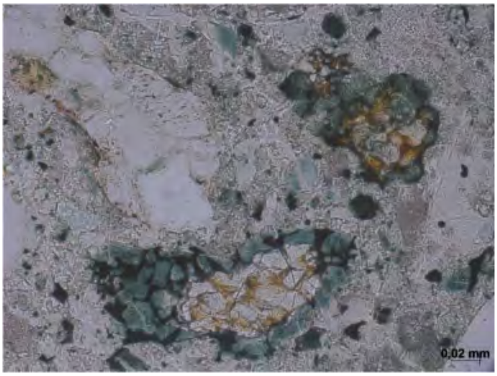

Figure 3. Microphotograph of blast furnace slag particles in the cement paste of concrete from the Northern Lock.

The engineers of the 1920s clearly did not shy away from pragmatic experiments with concrete mixes. A specific problem was posed by concrete sheet piling. The works required many more of these than foreseen. The solution was found in casting sheets using calcium aluminate cements ('ciment-fondu'). The use of this cement was neither allowed in the 1918 G.V.B. nor in general usage at the time of construction. Yet, its assumed good resistance towards seawater and sulphates in combination with how after 24 hours it had already achieved a strength which Portland cement only attained after four weeks (Betonvereeniging 1929) were ideal under the circumstances given. The sheets could be driven into the soil after only four days of hardening (Tellegen et al. 1924). Nevertheless, usage of this cement would always remain rare in the Netherlands.

4 LEGACY OF THE NORTHERN LOCK

The Northern Lock of the North Sea Canal in IJmuiden is functional and is currently again undergoing expansion and thus maintaining as intended its support for the port of Amsterdam. Less obvious but not less relevant is its legacy for Dutch concrete technology. The experience gained with testing binders, both their quality and durability when exposed to sea water, disseminated into Dutch practice. Whilst at the beginning of the works, experts such as P.W. Scharroo, then captain later colonel in the Dutch Army Corps of Engineers, a renowned expert on concrete, still cautioned (after admitting the good quality of German blast furnace slag cements): "Especially the latter (i.e. the good quality) cannot be emphasized enough, as blast furnace slag cement remains a dangerous material" (Scharroo 1925), the successful use of blast furnace slag cement at the Northern Lock eased its acceptance. Already in 1926, "the use of blast furnace slag, Portland-slag and slag cement has strongly increased in this country in recent years" (anonymous 1926). It affected Dutch building regulations as a precedent for utilisation of blast furnace slag cement, which was allowed under restrictions in the 1930 G.B.V. edition of the reinforced concrete regulations. In 1929, when introducing standards for cements, a standard for blast furnace slag cement N 484 was also published. In 1932, the company CEMIJ was established in IJmuiden as a joint venture between the Dutch cement producer ENCI, itself established in 1928 (now part of HeidelbergCement) and the steel producer Hoogovens founded in 1918 (now part of TataSteel), combining their respective Portland clinker and slag to factory produced blast furnace slag cement (Heerding 1971). Becoming less dependent on cement imports was important as well as, for example, a German-Belgian syndicate (Nederlandsch Cement Syndicaat) strongly influenced cement imports into the Netherlands.

Lea and Desch (1935), as contemporaries, already stated that the Netherlands had become a major user of blast furnace slag cement; a noteworthy transition from a strong opponent to world leader within a few decades. This observation is still valid today.

The infrastructure established for the enlargement of the canal played a factor in locating the first Dutch factory for blast furnace slag cement CEMIJ next to the harbour in IJmuiden in 1931 (anonymous 1931).

The research carried out for the Northern Lock and its use of trass, including specific mix designs, served as a reference for the German trass producer TUBAG (Trassforschungsinstitut der Tubag, 1934). From 1929 onwards, TUBAG sold blends of both Portland cement and blast furnace slag cement with trass, a product advertised for hydraulic works due to its low heat development (anonymous 1964).

Though a new lock is currently being constructed again, the old one still exists and the Northern Lock has continued to be a living lab for a century as in situ experiments continued to demonstrate the durability of its concrete proofing over this timespan.

5 CONCLUSION

The Northern Lock in IJmuiden represents a major hydraulic engineering work in Dutch construction history but it is also a unique project in developing concrete technology in the Netherlands and abroad.

Whereas until the 1920s, Dutch concrete technology still depended strongly on foreign knowledge, testing equipment and imported cements, in the 1930s it began leading the research of concrete in marine environments and common usages of blast furnace slag cement. The sheer amount of concrete used for the Northern Lock in combination with systematic quality control and prior testing returned evidence for the good performance of innovative cements. Also, the challenges arising when working with cements originating from different countries supported the need for the introduction of standards.

Close to its hundred years anniversary, the Northern Lock still offers new insights into the long-term performance of different concrete mixtures and cements, exposed and evaluated under the same aggressive conditions.

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History of Construction Cultures – Mascarenhas-Mateus & Paula Pires (eds)

A reinforced concrete stage tower within a 18th-century masonry theater: The Municipal Theater of Bologna

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ABSTRACT: The Municipal Theater is one of the main artistic symbols of Bologna. Although it is recognized worldwide for its musical history, its construction peculiarities are less known. The original building was designed by the architect Antonio Galli Bibiena in 1763 in a masonry and wood structure. The stage tower, burnt down in 1931, was rebuilt with a reinforced concrete structure, which is currently a significant landmark in the heart of the University district with about 35 m height. The reconstruction project, designed by engineer Armando Villa, faced complex issues for the emerging, but still inexperienced, Italian reinforced concrete technique, such as the installation of a large span roof at considerable heights. Archival research and digital documentation made it possible to analyze the structural concept of this construction, a significant example of the building culture of the 1930s, tracing the evolution of this specific construction system and contextualizing it on the international scene.

1 INTRODUCTION

The Municipal Theater of Bologna (1931–35) stage tower is a meaningful example of the evolution of construction techniques from traditional to modern architecture. On the one hand, the building expresses the research development on reinforced concrete in the Italian and international landscape in the early 20th century. On the other hand, it concerns the relationship between engineering and architecture in modern construction and the contemporary use of new techniques and new design language, with further confirmation, even in the 1930s, of the Italian concept of traditionalist construction.

The introduction of the reinforced concrete frame system in Europe at the end of the 19th century led to the quick substitution of masonry structures. This substitution also gradually happened in Italy, where the new technique was widely and rapidly spreading, with the substantial difference that Italian reinforced concrete structures initially consisted of a mixed structure (Del Piano 1937). The new system did not instantly result in the loss of traditional language linked to wall construction, but the insertion of structural frames in buildings began to change masonry systems, leading to their decisive revision. Even though the mixed construction did not affect the traditional style of buildings, it started to modify their spatial conformation and the new functional needs that it could satisfy (Poretti 2007).

The following phase of great experimentation was made possible by remarkable progress achieved in the scientific and technical field, such as understanding the inapplicability of elastic theory to an anisotropic material, the need for deepening research on plastic behavior, and the understanding of cracking and breaking phenomena. After all, Italian engineering had been univocally directed at improving the knowledge about reinforced concrete structures since the late 19th century, and Schools of Application (*Regie Scuole di Applicazione per gli Ingegneri*) started to teach the new construction technique in the early 20th century. These schools, future technical universities, started to train civil engineers and architects all over Italy. Thanks to Silvio Canevazzi and Attilio Muggia's work, Bologna became a privileged didactic context (Mirri et al. 2019; Mochi & Predari 2012).

Therefore, the new technique's high potentialities started to be tested in construction sites of public works. It was not surprising that very sophisticated structures were hidden within architectures strongly linked to eclectic languages. For instance, it was the case of the covering of Politeama Theater in Prato (1921), and Cinema Augusteo in Naples (1926), both designed by Pierluigi Nervi, and generally in many of the coverings and galleries of cinemas built in those years (Poretti 2008).

This also happened for the construction of the Municipal Theater in Bologna. The compresence of wide volumes and historical characters is evident in the external facades. However, from a functional perspective, the reinforced concrete technique guaranteed benefits that other construction methods could not give, thus conserving traditional forms (Figure 1).

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Figure 1. The stage tower of the Municipal Theater of Bologna in 1935. Andrea Villa's private archive.

Figure 2. The stage tower and the piezometric tower in Bologna's landscape in 1935. Donati & Zanichelli Company's private archive.

Figure 3, 4. The fire almost destroyed the stage in 1931. Donati & Zanichelli Company's private archive.

2 THE MUNICIPAL THEATER OF BOLOGNA

2.1 *History of the theater*

The Municipal Theater of Bologna is a *unicum* among Italian-built heritage: it is one of the oldest examples of Italian masonry theaters, and it also offers an extensive repertoire of construction techniques from various ages.

Bologna had many public and private theater buildings in the 18th century (Quagliarini 2008). In this context, the Municipal Theater was built to replace the Malvezzi Theater, destroyed by fire in the old town in 1745 (Ricci 1888). The original design was by Antonio Galli Bibiena (1697–1774), who had thirty years of experience as a theater architect at the Imperial Court of Vienna (Ricci 1915). The construction consisted of load-bearing masonry walls and a timber trussed roof. However, because of a great controversy raised by the Accademia Clementina Bolognese and some serious financial difficulties, the challenging project was only completed in 1763. It was downsized, resorting to simpler decorations, smaller stage dimensions, and some construction modifications that brought arly deterioration to the building e (Bergamini 1966; Ricci 1884).

The Theater's deterioration was so critical that many repairs and maintenance works were carried out between 1818 and 1820 under municipal architect, Giuseppe Tubertini (Giordani 1855). The roof of the stage was lifted to host more modern and sophisticated scenery designs, and Filippo Ferrari built a fascinating wooden machine to raise the floor of the stalls, bringing it up to the level of the stage and obtaining a single large hall to host events and costume balls. In 1854, the architect Carlo Parmeggiani restyled the building. Then, in 1866, the engineer Coriolano Monti designed the rear facade in a post-unification style (*Il Restauro del Teatro Comunale di Bologna* 1981). In the late 19th century, new rooms were added, and the heating and lighting systems were adapted to electricity.

After the fire in 1931, which almost destroyed the stage, substantial reconstruction works had to be performed: the previously mentioned reconstruction of the stage tower by the engineer Armando Villa and the main façade arrangement by the architect Umberto Rizzi in 1935. Villa designed a new autonomous reinforced concrete structure, considerably broader and higher than the previous one, adding a piezometric tower for fire safety (Villa 1936).

The last substantial interventions took place between 1980 and 1981 when the oldest parts of the building were restored (Pozzati et al. 1982; Zangheri et al. 1981). Nowadays, the building forms the core of the strategic center in the University area, planned as an artistic and cultural district of Bologna (Figure 2).

2.2 *Reconstruction of the stage tower (1931–1935)*

In November 1931, a dangerous fire almost destroyed the Municipal Theater's stage (Figures 3, 4). Newspapers of the time report that flames ruined only the stage thanks to the iron safety curtain, entirely saving Bibiena's great hall, which otherwise would have been destroyed because of its highly combustible wooden structures (Ricci 1931).

The reconstruction of the stage was considered an opportunity to carry out a series of significant works, such as a new fire safety system and the Theater's

Figure 5. The reconstruction of the stage tower. Donati & Zanichelli Company's private archive.

adaptation to the new technical-artistic needs emerging in that period. A larger space was required on the stage for scenery maneuvering, and a higher covering was necessary so that the top backdrop could be placed at a height not visible to the audience (Ufficio Tecnico del Comune di Bologna 1932). The Technical Office of the Municipality of Bologna drew up a preliminary project, defining the maximum size of the new building, materials, and other essential construction data. Many projects were presented, and a lengthy discussion started about the type of construction to adopt for the new stage. The most cost-effective solution was chosen to improve both the spectators' enjoyment and the backstage maneuvering conditions. The design was commissioned to Villa and the execution to Donati Agostino & Figli company (Ufficio Tecnico del Comune di Bologna 1933a).

Armando Villa graduated in Bologna in 1920 and was fascinated by the emerging reinforced concrete technique; he designed many challenging and daring works during the first half of the 20th century. (Villa 1983). The engineer seemed to have understood the principles and critical issues of the reconstruction project and wrote: "While our entertainment halls are in general perfect for their sonority and aesthetic beauty, the same cannot be said about the stages, which have low overall dimension and are often in wood for the most part. Very high costs are incurred to make them more modern, […] to raise rooms with expensive masonry structures, and to equip them with increasingly improved but at the same time expensive systems" (Villa 1936).

Following his way of thinking, Villa's proposed solution was remarkably valid for the building culture of the '30s. It consisted of reinforced concrete frames that caged existing masonry walls (Figure 5). The first phase included demolishing masonry over 15 meters high, which had been burnt by fire, replacing two old masonry pillars with a reinforced concrete one to make maneuvers easier in the backstage (Ufficio Tecnico del Comune di Bologna 1932).

The design of the roofing system required special attention because of its considerable size. In the 1930s, many innovative solutions for realizing large span roofs at considerable height were presented in the European context. For instance, the Baroni-Lüling patent and the Mélan system used reinforced concrete trusses without adopting expensive temporary supporting wooden structures (Campus 1932; Santarella 1931). Armando Villa analyzed these techniques and proposed his original reinterpretation to build the Municipal Theater's covering-trusses.

3 ARCHIVAL RESEARCH AND SURVEY ACTIVITIES

A cross-analysis was carried out between archival sources (historical photographs, preliminary and executive drawings, reports, structural calculations), geometric information (from the digital survey made in 2019), and photos (from various inspections) to understand the construction peculiarities of the entire building.

The archival research has been conducted in several public archives (Archivio Tecnico Comunale, Archivio Storico Comunale, Biblioteca dell'Archiginnasio, Archivio di Stato), and the private archives of the Armando Villa's heirs and the Donati Agostino & Figli Company (respectively Andrea Villa and Donati & Zanichelli S.R.L.). However, some original drawings could not be examined due to their state of deterioration.

An accurate TLS survey of the Theater's stage tower has been carried out with a *Faro Cam2Focus 3D®* laser scanner. The survey campaign took three working days, and it was necessary to shoot 242 scans. Many high-resolution scans were necessary due to obstacles between the structures, for example, air conditioning systems, electric cables, maintenance walkways, and especially the high number of backdrops hanging from the top of the stage tower. Alignment of scans was made through *Faro Scene 2019®* software. Despite the complexity and occlusions of the surveyed space, it was possible to achieve an extremely accurate alignment.

A large amount of geometric data from the TLS survey allowed the realization of a 3D model in *Rhinoceros®* software (Figure 6). Thanks to the 3D model and the point cloud, it was possible to understand the building dimensional aspects by making direct measurements, extrapolating orthophotos, and moving virtually inside the Theater's rooms.

4 CONSTRUCTION CHARACTERISTICS

Armando Villa made some changes to the original project during both tender and construction phases, which can be grouped into the preliminary design and as-built. While the planning evolution was studied exclusively through archive research, the correspondence between design drawings and the built construction was verified through the field inspections and comparison with the laser scanner survey output.

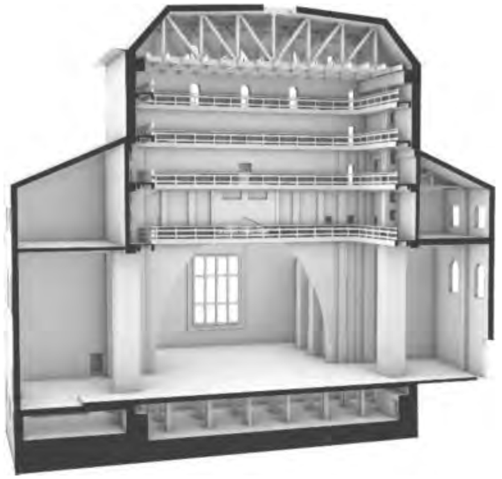

Figure 6. Perspective transversal section of the 3D model of the Municipal Theater's stage tower (© 2020, Beatrice Salmi).

4.1 *Preliminary project*

The reconstruction project faced complex issues for the emerging, but still inexperienced, Italian reinforced concrete technique. These include the connection between the old and the new built volumes, the installation of a large span roof at considerable height, the design of a structure capable of withstanding the heavy mobile loads of the scenography, and ensure very high fire resistance.

4.1.1 *Covering system*

As mentioned, temporary wooden structures, which were usually used to support the construction of reinforced concrete trusses in that period, would have been costly for a span of 25 m and an installation height of 30 m. For this reason, Villa initially intended to use the Baroni-Lüling patent (Villa 1933a). This system provided a semi-rigid metal reinforcement (withstanding the formwork and the service bridges) prepared on the ground and then raised to the support level, avoiding temporary structures. This patent was adopted, for example, for the roof of the Diana Summer Theater in Milan (Santarella 1931). However, Villa considered Baroni-Lüling's reinforcement insufficiently rigid because it was made only of metal rods spaced by bolted plates. So, he decided to adopt a more rigid metal structure using section bars and properly shaped elements to realize the reinforcement of the trusses.

Villa's solution can therefore be interpreted as an adaptation of the Mélan system, which was widespread in Europe since 1892, initially for vaulted ceilings, and later for arched bridges (Barazzetta 2004). This system avoided the construction of slight arches using temporary pillars, using the load-bearing capacity of a metal framework reinforcement made of steel profiles, supporting the formworks. This reinforcement was then incorporated into the concrete with other reinforcing bars, contributing to the resistant capacity (Giuggiani 2016). Another example of the application of the Mélan system in a similar building in Italy is the reconstruction of the Teatro San Carlo roof in Naples in 1928. This project was presented in 1930 at the First International Congress of Concrete and Reinforced Concrete in Belgium (Campus 1932).

It is possible to assume several reasons for Villa's technical choice. First, the tender specifications required a reinforced concrete structure to ensure fireproofing safety. Also, a more rigid rebar structure – which allowed obtaining a higher moment of inertia and a good concrete constraining – could support loads both during the construction and the life cycle of the building. Villa's solution offered the possibility of casting the concrete at the installation height and not on the ground, so metal trusses were lighter to lift than same-sized trusses in reinforced concrete. In this way, it was possible to cope with most of the construction problems: a complex construction site located in the historical center, the structural continuity and the fireproofing of the stage tower structures, and the reduction of vibrations induced by the pull of the theatrical machines.

The calculation reports (Villa 1933a) express the thought with which the engineer conceived the work. At first, axial stresses in rods were computed using the Cremonian-diagram method, assuming hinge constraints at joints. Next, bending stresses caused by purlins at the truss extrados were evaluated. In this case, the joints were considered semi-fixed constraints. The L section bars show the adopted calculation method. It was executed according to three different load assumptions: the weight of the beam during the hardening of the concrete, plus the weight of the formworks and the service bridges (construction phase), the weight of the fully casted beam, including the weight of the roof and lattice boardwalk during the in-use phase, the fully loaded beam, including the weight of the snow and the pull from backstage machines (Villa 1933a).

According to the Italian construction regulation of the time (Regio Decreto-Legge 1932), the calculations took into account the steel strength equal to 1200 kg/cm^2, the concrete bending strength equal to 40 kg/cm^2, and the concrete bending strength equal to 50 kg/cm^2. Tensioned steel elements were dimensioned considering a zero tensile strength of the concrete (Villa 1933a).

Villa proposed two different geometrical solutions. The first consisted of English-type triangular trusses (Figure 7) as required by the tender specifications; the second consisted of a Pratt truss with parallel stringers that allowed improving the space between the timber lattice floor and the roof (Figure 8). The roof design resorted to a new construction system for the Italian territory, where the steel trusses, made with welded steel angles, were coated with concrete, becoming the reinforcement to the final reinforced concrete structure.

Understanding this extraordinary engineering work is possible only by analyzing the site construction

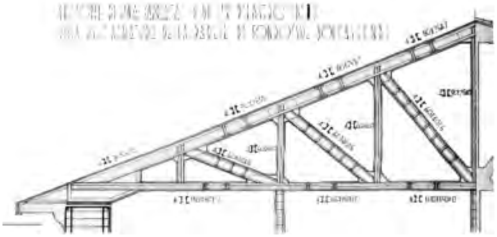

Figure 7. Preliminary solution with triangular trusses. Andrea Villa's private archive.

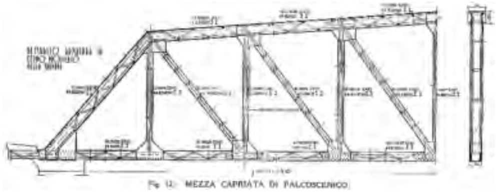

Figure 8. Preliminary solution with polygonal girders. Municipal Technical Archive of Bologna.

Figure 9. The load test of the metal beam. Donati & Zanichelli Company's private archive.

Figure 10. The lifting towers of the metal beam. Donati & Zanichelli Company's private archive.

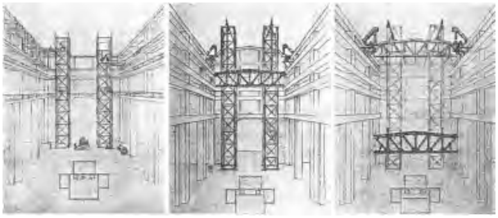

Figure 11. The phases of lifting the metal beams. Municipal Technical Archive of Bologna.

Figure 12. The roof skylight. Donati & Zanichelli Company's private archive.

methods and their peculiarities and characteristics. After a load test, the metal beams were assembled on the ground with the formwork (Figure 9). They were then raised to a height of 30 meters by the wooden towers used to lift and distribute materials, anchored on the wall between the stage and the back façade (Figures 10, 11). In this way, the assembly of the trusses could be done simultaneously with the new reinforced concrete frames and the masonry consolidation. Since the balconies' presence did not allow the truss to be lifted as a whole, the two lateral support triangles were lifted in advance, and then the rest of the truss was bolted to them. Once the purlin overhead formwork was assembled, the concrete could be cast. In this way, the trusses were connected by a double ribbing: purlins on top and timber lattice floor at the bottom.

Concerning the roof, its central part was equipped with a large skylight (Figure 12) to create a sort of stack effect in case of fire, carrying away combustion smoke. The Perret system was proposed to protect the hollow brick roof slab from temperature variations that could occur in case of fire. It was made of a double-layer, reinforced concrete slab with an interposed air chamber (Villa 1933b).

4.1.2 *Elevation structures*

A new, reinforced concrete frame was designed to cage the existing masonry structure and to raise it. It consisted of pillars, beams, and balconies. The tender specifications required reinforcing some existing pillars and other replacements to make the lateral rooms more easily accessible.

The existing masonry pillars were strengthened with reinforced concrete up to the height of the first balcony through a horizontal edge beam of 30 cm and vertically connected by pillars of 30 × 30 cm, made in adherence to the masonry (Figure 13).

Figure 13, 14. The reinforced masonry pillars. – The pillars with the Vierendeel shape. Donati & Zanichelli Company's private archive.

Figure 15. The consolidation and caging works of the wall. Donati & Zanichelli Company's private archive.

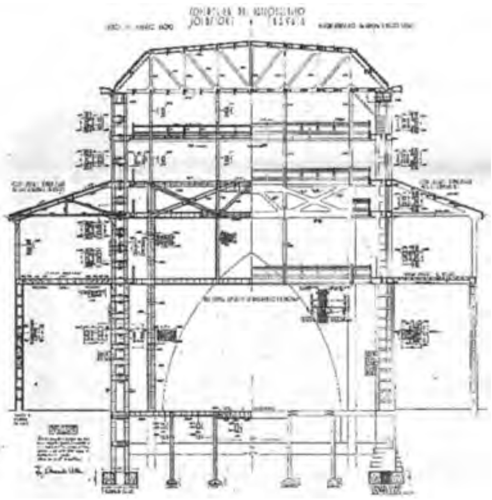

Figure 16. Transversal section of the final project of the stage tower of the Municipal Theater. Covering solution with polygonal trusses. Municipal technical archive of Bologna (Villa 1936).

The new pillars were designed in reinforced concrete. Instead, in contrast to what was initially assumed, they were built of reinforced masonry up to the first balcony level (Figure 13), like the existing ones, to avoid differential subsidence phenomena (Ufficio Tecnico del Comune di Bologna, 1933b).

Over the first balcony, all pillars are raised up to the roof installation height. Due to the significant influence of the wind action, which involves high bending and shear stresses, a rectangular cross-section of 150 × 90 cm was initially dimensioned. A different morphology was adopted during construction since full, cross-section pillars with this size would have been unnecessarily heavy. The new pillars defined an original shape with four external elements tapering upwards, connected by beams, which were shaped according to a spatial "Vierendeel-like scheme" (Figure 14). In this way, it was possible to obtain a high moment of inertia, and a more efficient cross-section, reducing the weight of structural elements (Villa 1933a).

The horizontal connections between the frames consisted of tubular beams measuring 75 × 60 cm, while the top of the pillars was connected, at the trusses level, by a 150 × 105 cm tubular beam. Four balconies contributed to stiffen the structure, made of a 7 cm concrete slab.

4.2 *As-built*

The final project included the demolition of masonry walls higher than 15 meters, burnt by the fire, and the consolidation of the remaining ones, preserved for acoustic requirements. In particular, the wall that divided the stage and the great hall was caged by a reinforced concrete frame, consisting of two pillars of a 60 × 30 cm section, connected by tubular beams of 75 × 60 cm and by the reticular beam of the proscenium. The wall thus behaved as a slab under the action of the wind. A similar intervention was carried out on the wall separating the stage from the backstage, where the ogival masonry arch was preserved (Figure 15).

The preliminary proposal to realize the reticular truss roofing was accepted by the Municipal Administration (Figure 16). Villa designed four identical trusses with a constant spacing to support the roof, and two of them are not supported by an underlying pillar (Figure 17). He tried to connect and stiffen the ring beam at the top of the pillars to guarantee better support to the two mentioned trusses and have an intermediate element to realize the complicated joint between these particular trusses and the Vierendeel-shaped pillars.

Therefore, the frame assumed in the preliminary phase and calculated to withstand the wind action was not built and the final project aimed to exploit the capabilities of the structure differently. Villa tried to give the four walls a monolithic shear wall behavior by realizing stiffening elements in reinforced concrete collaborating with the masonry infill. Three external balconies were built in addition to the elements already

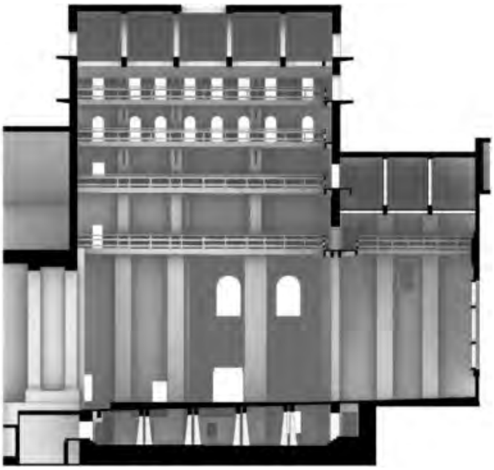

Figure 17. Longitudinal section of the Municipal Theater's stage tower. (© 2020, Beatrice Salmi).

provided (pillars, balconies, tubular beams, and concrete lattice floor beams).The new structure required a continuous foundation, which complemented the existing ones, consisting of isolated elements and masonry arches. Villa reported that once the excavations had been carried out, the existing isolated plinth foundations were slightly modified to create a continuous reversed beam with good cross-section and reinforcement. Subsequently, underground foundation walls were built under all foundation masonry arches and buttresses to merge the existing foundations into the new ones and to consider them supportive and collaborating with the new structure. The final solution adopted for the stage plan was particularly original. Four RC main beams were realized with a mirrored cross-section, parallel to the proscenium. Six pillars in reinforced concrete supported each beam, split in the middle to lower backdrops or other scenery devices along its entire length. Later on, the void between these RC frames was suitably reinforced by a metal cross-bar bidirectional frame supporting a wooden slab in the stage. This solution is therefore capable of hosting, for scenery needs, trapdoors, and other scenery artifices.

The engineer also paid particular attention to the fire safety project. First, he adopted design solutions to create a partitioning system acting as a firewall that could isolate any fires on the stage from the room and vice versa. To this end, a new iron safety curtain was installed, and the orchestra pit was made of reinforced concrete. Automatic hydrants and sprinklers were installed as fire protection devices. Two water tanks were built to meet the water demand. The first one was underground, and the second was a hanging tank with 80 m^3 capacity and was designed to ensure enough water pressure. This 44 m high piezometric tower recalls the design of the pillars in the stage tower. It consists of four RC pillars connected crosswise to resist bending caused by wind. Internally the composed pillar is empty to host the boiler smoke duct passage. It rests on a wide foundation base, consisting of two strongly reinforced plates of a one-meter thickness (Villa 1936).

5 CONCLUSION

The importance of the Municipal Theater of Bologna emerges in the field of construction history as well as its cultural and artistic history, bringing to light a hidden chapter in the evolution of reinforced concrete techniques in the 1930s. As it is well known, studies on the subject have usually examined the so-called "exemplary buildings" or "famous designers".

The works carried out by lesser-known designers can instead constitute a new horizon for research, contributing, on the one hand, to confirm the knowledge already acquired, and on the other, to follow new paths to explore the history of the development and diffusion of reinforced concrete.

The work of Armando Villa confirms the Italian trend to combine the new material with solid masonry structures. It also simultaneously shows excellent awareness of the properties of reinforced concrete and some of its limitations. The engineer could combine existing and innovative solutions to meet both the requirements of the tender specifications and the structural, safety, and functional needs that a theater stage tower required.

The documentary, historical research, matched with modern digital survey techniques, made it possible to discover a piece of the Bolognese reinforced concrete history, creating the basis for verifying whether this work influenced theater buildings in the rest of Italy and Europe and vice versa.

Although the adopted solution was designed when reinforced concrete frames were being used in the most important constructions throughout Italy, it shows that this material was mainly used to solve practical construction problems and not to give more relevance to the architectural appearance of buildings. In this case, the reconstruction project aimed to integrate a new structure with existing masonry walls, raising the old structure to create a larger space for scenery maneuvering. Therefore, the reinforced concrete was recognized as the construction technique that best satisfied this purpose.

ACKNOWLEDGMENTS

We want to thank the management and the entire staff of the Municipal Theater of Bologna, who guaranteed access to the building, providing indispensable cultural and operational support for the activities carried out. This research is part of a series of activities jointly carried out between the research group of the Department of Architecture and the administration of the Theater, which is currently underway. We also want to thank Andrea Villa and the Donati & Zanichelli Company for their willingness to share archival documents.

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History of Construction Cultures – Mascarenhas-Mateus & Paula Pires (eds)

Wooden Structures by G. G. Karlsen and the Derevyagin beam

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ABSTRACT: There are various ways of joining pieces of timber together – pegs, dowels, keys, nails, screws, bolts, connectors and glue. The connection problem is more difficult when large forces are involved, as for example transmitting horizontal shear force in built-up beams. The development of glued-laminated timber beams after strong, durable glues were invented during the Second World War would seem to have solved the problem. In 1967, a book entitled *Wooden Structures* edited by Professor G. G. Karlsen was translated into English from the Russian and published in the West. It revealed that timber technology in the USSR was remarkably advanced in some respects. The Derevyagin beam, invented by V. S. Derevyagin in 1932 and described in *Wooden Structures*, uses oak keys, proportioned for maximum efficiency to connect the separate pieces of a built-up beam with no glue. The use of glue is now being questioned on health and sustainability grounds. The Derevyagin beam, an elegant piece of engineering, shows that it is possible to make built-up timber beams without the use of glue.

1 INTRODUCTION

The main problem of timber structures has always been joining the pieces together. Carpenters before the widespread use of metal had their traditional jointing methods. To locate and fix the timbers at the joints they used pegs and dowels. In Britain and elsewhere the pegs were an important component of the medieval timber frame. In Russia there was also a tradition of nail-less construction. The vernacular timber log-on-log buildings with the coursed logs interlocking at the corners needed no metal. The “bezgvozdevaya krysha” was a “roof without nails” (Opolnikov 1989). In Britain, large oak dowels called trenails were used in Victorian timber structures such as bridges and roofs to connect the thick laminations (Bell 2015).

As iron became commonly available, nails, screws and bolts took the place of pegs and dowels. The professional engineer in the first half of the 20th century was conditioned to think in terms of steel and concrete. Structural engineering theory was taught with the emphasis on the analysis of frames and beams in these materials. Timber would be unlikely to be considered as an option for any but the smallest structure.

Engineers have an understandable liking for steel. Its properties are reliable and fairly well defined; it is strong and ductile. However, there is a mismatch when it is used in conjunction with timber. A steel bolt is stronger relative to the surrounding timber and the allowable load is often defined by the weaker material. Various ways of overcoming this were invented: toothed-plate, split-ring and shear-plate connectors spread the load from the steel bolt into the timber over a wider area, but these were not easy to use and were not widely adopted.

After the Second World War (or Great Patriotic War), reliable glues became available. Glue was increasingly seen as the answer to many disparate engineering problems such as aircraft fuselage construction, repairs to old timber structures or strengthening concrete viaducts. Timber engineering revived with the advent of glued-laminated beams that solved the problem of creating long, deep members for roofs. They also looked attractive and were successfully received and promoted by architects. The idea of making built-up timber beams without glue using other pieces of timber as connectors does not come easily to the modern structural engineer.

2 WOODEN STRUCTURES

In 1967 a book entitled *Wooden Structures* (Figure 1) edited by Professor Genrikh Georgievich Karlsen was translated from Russian to English and published in the West. It is based on the 1961 Russian edition. There were 12 editions of the book published between 1952 and 1967 in three languages. It was the product of research in the USSR in the Department for Wooden Structures (formed in 1928 under Karlsen), which was part of the State Research Institute for Structures.

It is much more than a code of practice or a textbook, being virtually an encyclopaedia of timber engineering. It covers every aspect of wood – fire-resistance, preservation from biological attack, the calculation and design of structures of all types, joints, the timber industry, machines and tools, sawmills and seasoning. It reads like an intermediate stage between the handbooks of the 19th century and a modern textbook. With the help of *Wooden Structures* you can design a

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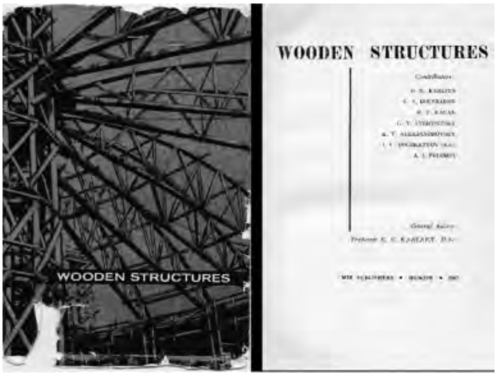


Figure 1. *Wooden Structures* cover and authors.

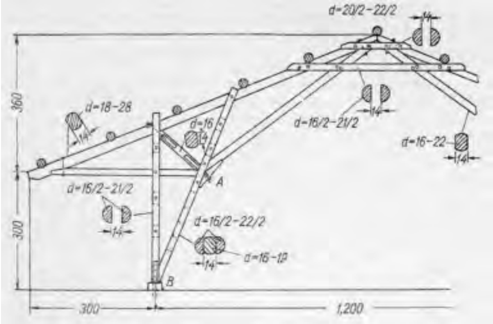


Figure 2. Design for the All-Log Construction of a 12-m span shed.

Howe-Zhuravsky highway bridge, a guyed radio mast, a lattice vault, a stressed skin panel, a timber frame house or a panelled door. Timber scaffolding and centering for bridges are covered. The centering for the dome of the Novosibirsk theatre is illustrated. The section on Glulam arches begins with reference to the problems of Emy's early-19th-century work in France, which is surprising in a manual of the 1960s. The six other authors in addition to Karlsen account for the diverse style and content.

The theoretical approach to the fundamentals of design calculation in *Wooden Structures* is modern, using limit state principles, with separate factors applied to the loads. The change to limit state design did not start to take place in Britain until the 1970s for concrete and for timber not until the 21st century. The authors are happy to use plastic stress distributions and ultimate load design in their analysis. They are also happy with some approximate solutions and, when necessary, use a suitable coefficient to take into account an effect that they cannot quantify more accurately. This approach is very different to the computer-orientated methods now in general use. In contrast to its advanced theoretical approach *Wooden Structures* illustrates some quite primitive-looking designs and methods. Logs rather than squared timbers are frequently used, for example in large sheds, in the legs of towers and the decks of bridges (Figure 2).

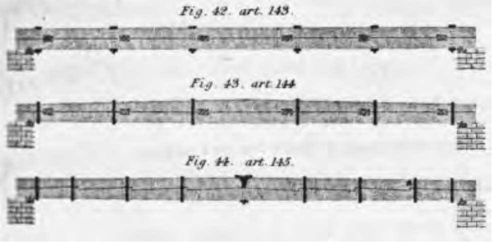


Figure 3. Tredgold keyed and notched beams.

More surprising is the Kashkarov method of assessing the strength of timber described in the book. In this method, a small-bore rifle is fired at a specimen and the strength of the timber is derived from the relation with the depth of penetration of the bullet (under winter conditions the timber specimens are tested after thawing out). Although written by academics, *Wooden Structures* adopts an intensely practical approach to timber engineering.

3 THE PRECEDENTS FOR BUILT-UP BEAMS

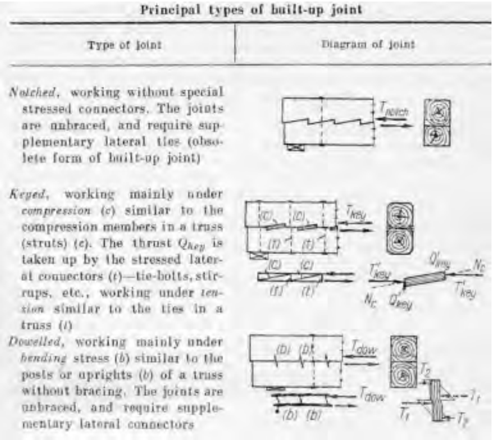
Prior to the 20th century, various methods were proposed for making built-up beams. Alberti and Francesco di Giorgio had designs for beams with notches and iron straps in the 15th century (Mainstone 1975). Leonardo drew notched beams connected by bolts (Giunchi et al. 2003). The base beams of the 21-metre roof trusses of Wren's Sheldonian Theatre (1662) are made up of timbers joined together with vertical notches and bolts. Jacob Leupold in *Theatrum Pontificale* illustrated notched beams and keyed beams in 1726. Tredgold has many designs for beams with notches and keys (Figure 3) in his 1820 *Elementary Principles of Carpentry*, the last impression of which was published in 1946 (Booth 1979).

Brunel in 1841 experimented with built-up beams trying different combinations of bolts, dowels and inclined keys (Pugsley 1976). Rankine in *Civil Engineering* has similar keyed beams to Tredgold and other examples of beams with diagonal keys and bolts. All these beams look difficult to fabricate and lack theoretical consideration.

In *Engineering Construction in Steel and Timber* (Warren 1921) there are drawings for 24-foot span railway viaducts with three main beams of two 12-inch square hardwood timbers connected with diagonal keys. The calculations include justification of the forces and stresses on the keys and the vertical bolts.

Wooden Structures deals with the different types of built-up beam joints (Figure 4). The notched and keyed beams are noticeably similar to those in Tredgold and Warren. The Dowelled joint (Figure 4), which is the basis for the Derevyagin beam, is a quite different and original idea. These beams are likened to trusses with uprights and no diagonal bracing, an imaginative analogy.

The keyed beams are considered in some detail (Figure 5), but the conclusion is reached that they cannot be recommended for use in structural timber, being unsuitable for modern constructional methods.



Principal types of built-up joint

Type of joint	Diagram of joint
Notched, working without special stressed connectors. The joints are unbraced, and require supplementary lateral ties (obsolete form of built-up joint)	
Keyed, working mainly under *compression* (*c*) similar to the compression members in a truss (struts) (*c*). The thrust Q_{key} is taken up by the stressed lateral connectors (*t*)—tie-bolts, stirrups, etc., working under *tension* similar to the ties in a truss (*t*)	
Dowelled, working mainly under *bending* stress (*b*) similar to the posts or uprights (*b*) of a truss without bracing. The joints are unbraced, and require supplementary lateral connectors	

Figure 4. Classification of built-up beams.

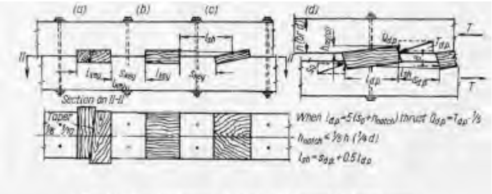


Fig. 54. The development of joints with prismatic (linear) keys

Figure 5. Beams with keyed joints.

4 THE DEREVYAGIN BEAM

The Derevyagin beam consists of squared softwood timbers (baulks) connected with plate-like oak dowels, more succinctly called keys (Figure 6). Two or three baulks are connected and the natural run-off of a tapered baulk can be accommodated. The keys must have their grain running perpendicular to the horizontal joint. There are limits on their spacing and height to prevent splitting or weakening of the baulks. The sizes of the keys are generally standardized so that they satisfy the design criteria.

Dowelled joints are extensively described and analysed in *Wooden Structures*. Clearly there had been a lot of experimental research. The tables in the book for cylindrical dowels cover oak as well as steel, which is unusual. Failure in the oak dowels is due to bearing on the timber of the dowel or bending of the dowel; failure in shear across the grain of the dowel is not critical. The softwood baulk timber is stronger in compression parallel to the grain than the oak dowel is in bearing perpendicular to its grain.

The forces and stress on the keys in a Derevyagin beam are shown in Figure 7. The bearing stresses on the key develop shear and bending in the key. As the forces increase it will deform and fail. The design load capacity is dependent on the lesser of the bearing or the bending mode of failure. With the right proportions, as in the standard keys, the limit is reached at the same load for both modes. This is an elegant piece of engineering but perhaps only visible to engineers. As Shukov, another very talented Russian engineer, said: “Engineering is thankless because you have to possess knowledge to understand its beauty”. Steel keys would not greatly improve the load-carrying capacity of the joint since the stresses on the baulk timber would become the controlling factor. An advantage of timber keys rather than steel is that they can be made

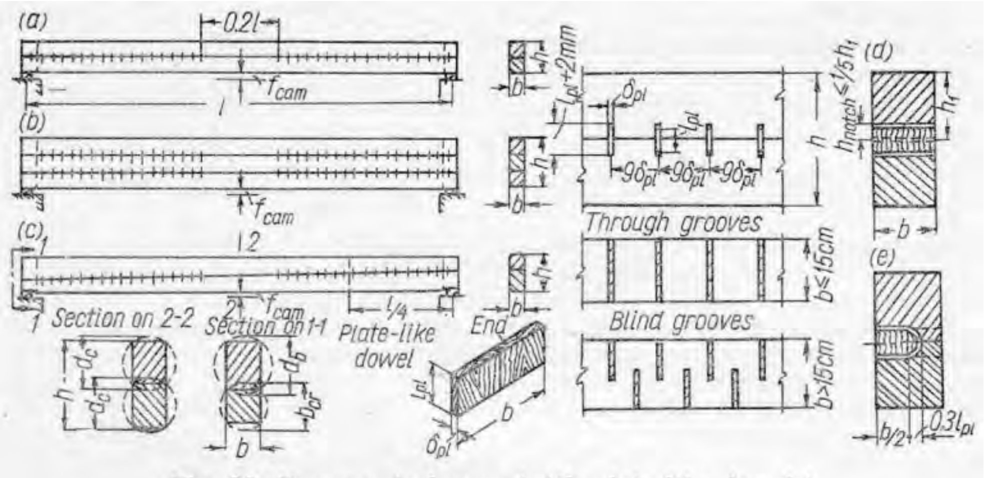


Fig. 90. Derevyagin beams (with plate-like dowels)

Figure 6. Derevyagin beams.

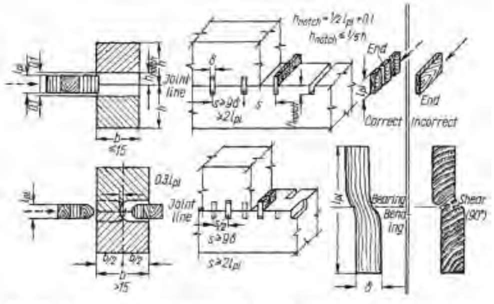


Fig. 59. Geometrical characteristics of normal connections using oak plate-like dowels

The standard dimensions of thickness (δ_{pl}) and length (l_{pl}) of a plate-like dowel (Derevyagin's plates) are 1.2 × 5.4 or 1.6 × 7.2 cm; the corresponding dimensions of the seating are 1.2 × 5.6 or 1.6 × 7.4 cm (the larger size is for timbers with a height greater than 20 cm)

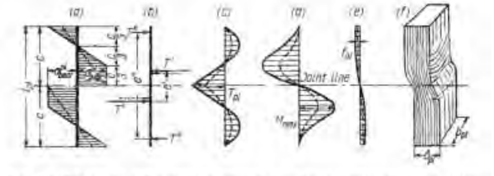


Fig. 60. The layout and stress diagrams of the elastic plastic stress condition of a normally embedded single-shear dowel, characterising the limiting conditions of a dowelled joint (the stress diagram of the elastic stage of the stress condition of the dowel is shown in dotted lines)

a—stress diagrams of σ_{bear}; b—T' and T''—resultants of σ_{bear}; T'v' = T''v''; c—stress diagram of Q_{dow} in the plane of the joint line $Q_{dow} = T_{pl}$; $T_{pl} = T' - T''$; d—stress diagram of M_{dow}; e—deformed centre-line of dowel; f—characteristic shape of the failure of an oak plate-like dowel of standard dimensions

Figure 7. Design and analysis of the keys.

to fit tightly. The moisture content of the keys can and must be substantially lower than the baulks so that the swelling across the grain helps to tighten the joint.

The criteria for the allowable forces on the dowels are set out in *Wooden Structures* and justified by the theory derived from Figure 7. There is some mismatch between theory and practice, which would concern an engineer searching for greater accuracy but it is explained away reasonably convincingly in the text. A computer analysis could reconcile the experimental and the theoretical more accurately.

The method of designing a Derevyagin beam is described in detail. First, the factored design load is found and the maximum bending moment derived. The required moment of resistance is calculated and modified by a coefficient to account for the pliability of the connectors. The coefficient depends on the span and the number of baulks. The total height of the beam is calculated knowing its width and therefore the height of each baulk. The beam is checked for deflection and another coefficient applied to the second moment of area to account for the keys. The number of keys needed is calculated using a modified distribution of the shear stress along the beam, redistributing the load from the most heavily loaded keys. The camber required is calculated with allowance for slippage of the dowels.

It is typical of *Wooden Structures* not only to explain how to design the beam but to show how to build it (Figure 8). The best timber is used for the lower timbers. Small vertical slits (kerfs) are cut in the bauks to prevent horizontal cracking. The keys are made from sound dry oak. The beams are made in a workshop or factory process but using light equipment. They are assembled in pairs on either side of a rotating transom. The baulks are pre-cambered using cramps and packing pieces A chain mortising machine is used to create the slots and the keys are knocked in with a mallet. The rotating transom allows for keys to be driven from either side of the beam. The tightness of the keys is essential.

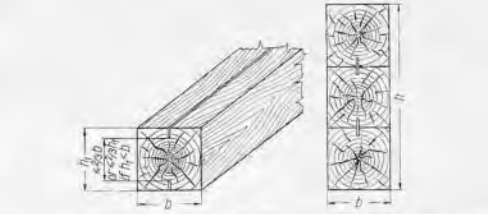


Fig. 91. Vertical saw kerfs in the balks in order to provide a safeguard against the appearance of horizontal cracks

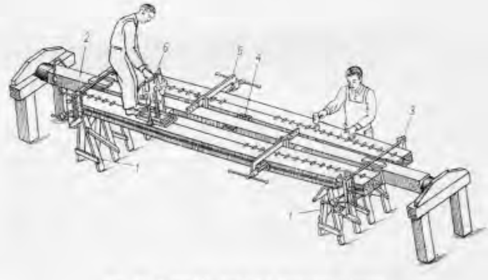


Fig. 92. Assembly bench for Derevyagin beams

Figure 8. How to make Derevyagin beams.

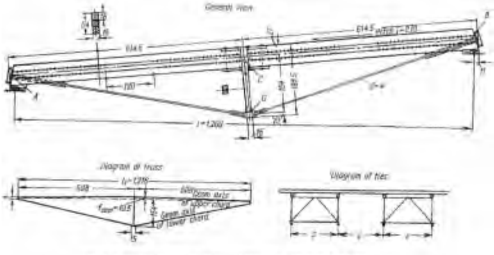


Fig. 131. Single-pitch (lean-to) trussed-beam truss with a span of 12 m

Figure 9. Truss design.

Wooden Structures has drawings of Derevyagin beams used in various configurations (Figures 9 and 10), where they look rather clumsy and heavy when incorporated into roof trusses. There is one photograph of the trusses for a roof with an 18-m span (Figure 11) similar to the Figure 10 design.

These trusses look quite difficult to make and the beams need a lot of calculation if not to a standard design. It would be interesting to know how often the beams were actually used, not perhaps easy to discover since the USSR was so huge and the types of buildings

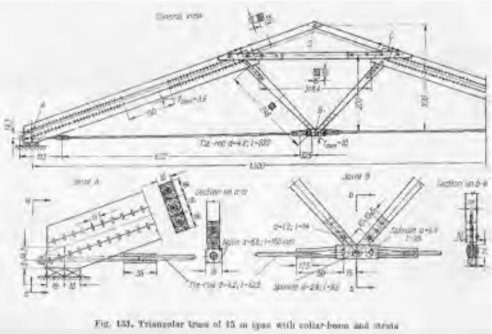


Figure 10. Truss design.

Figure 11. Built truss.

where they might be found could have been destroyed by war or obsolescence. Without that information it is impossible to know how successful the beams were in practice. The fact that they continued to receive so much space in the book 35 years after they were invented says something – but that might be that the engineers were still enamoured with the concept.

The Derevyagin beam is a beautiful example of manipulating the anisotropic behaviour of timber and the qualities of different species. Engineers, like other professionals, can allow themselves to be carried away by their enthusiasm. By the 1960s, glulam was readily available in Russia, as is shown elsewhere in *Wooden Structures*. Surely the authors would have been able to appreciate that the Derevyagin beam was a technological dead-end at that time.

One inescapable thought that occurs when looking at the three-baulk beam in Figure 8 is the resemblance to the log-on-log construction of a traditional Russian timber house, which is also illustrated in a contemporary version in *Wooden Structures* (Figure 12).

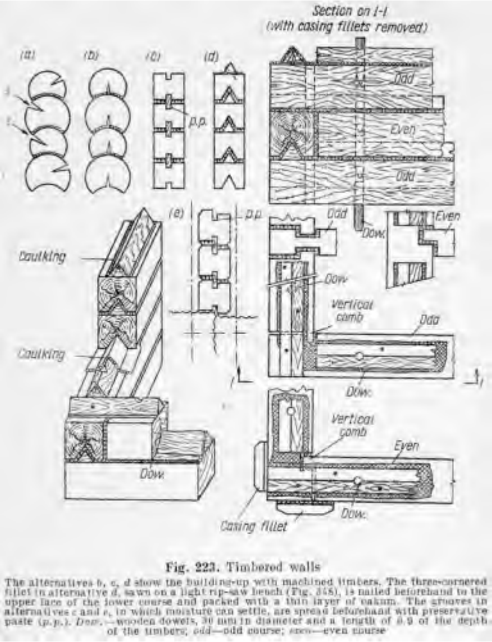


Figure 12. Log-on-log house construction.

5 THE CONTEXT OF WOODEN STRUCTURES

What prompted the USSR to publish *Wooden Structures* in English in 1967? It was a time of scientific and technological rivalry between the USSR and the USA, at its extreme in the Space Race of the 1950s and 1960s when the Soviet Union had astonished the world by its initial lead in space exploration. In 1968, *Strength of Materials* by V. I. Feodosyev and *Design of Metal Structures* by K. K. Mukhanov were also translated and published in English. The market for these books was unlikely to be in Europe or America which had their own codes of practice and textbooks. What was then known as the Third World, where English was widespread, was a more possible market. The Soviet Union was keen to increase its influence and these books were proof of its technological progress and desire to share and transfer its knowledge.

Wooden Structures seems to have made little impact in the West, at least in Britain. It was not reviewed in *The Structural Engineer.*

6 DESIGN OF METAL STRUCTURES

Design of Metal Structures (Mukhanov 1968) is a companion volume to *Wooden Structures*. It also uses limit state design at this early date but is much more like a Western textbook, dealing almost exclusively with design, as its title implies. It covers aluminium as well as steel in the one book, which is unusual. Welding and industrial structures occupy a large part, unsurprisingly given the Soviet push to industrialize. There is a reference to the importance of what must be an interesting document, *Rules for the Economical Consumption of Metal, Lumber and Cement in Construction (TII 101-61)* published by the State Building Committee of the Council of Ministers of the USSR, which infers some strategic if not political involvement in engineering decision making. There are some innovative designs using prestressed steel beams and guyed structures such as the USSR pavilion at the 1958 Brussels World Fair, another occasion for East-West rivalry.

7 THE PERSONNEL – KARLSEN, DEREVYAGIN, GOODMAN AND OTHERS

Genrikh Georgievich Karlsen (1894–1984), the editor of *Wooden Structures*, was the key figure in Soviet timber engineering in the 20th century. He graduated from the Moscow Higher Technical School in 1922. He became a professor in 1932, having founded the Department for Wooden Structures, which was part of the State Research Institute for Structures SNIPS in 1928. He wrote the first standards in the USSR for the design of wooden structures in 1929. He was the author of many books on timber but was also active in other areas. He was co-designer of the reinforced concrete shell roof of the laboratory building of the All-Union Institute of Electrical Engineering in Moscow in 1929 (Kurrer 2018) and wrote a book on the use of draught horses on collective farms. He was involved in military engineering, teaching at the V.V. Kuibyshev Academy of Military Engineering and serving in the army before and during the war. He received many awards including the Order of Lenin.

The State Research Institute was set up to promote the use of modern methods in accordance with Soviet policy. It attracted the most talented engineers – Felix Samuely, who was to become a celebrated engineer in Britain post-war, worked for a time in the Steel Structures section (Higgs 1960). This was exactly at the time (1930–31) when welding was being introduced there (Mukhanov 1968), and Samuely was a pioneer later in the 1930s in the use of welding in Britain (Yeomans 2003).

For some engineers, working in the State Research Institutes was a strategy for self-preservation in an intellectual sanctuary. In actual construction the blame for any problems or delays could be laid directly at the door of the engineer involved with unpleasant consequences. Approximately half of all engineers were arrested in the late 1920s (Graham 1993). To take one of many examples, Polygalin, the chief engineer for the construction of the Novosibirsk theatre, was executed (Nevzgodin 2018). Karlsen and his colleagues were working under the shadow of the purges.

V. S. Derevyagin was clearly an inventive engineer. Apart from his beam, he is credited in *Wooden Structures* with the proposal for metal-and-wood bowstring trusses with a segmental upper chord. The members in the upper chord have a notch in the top at the joints. The eccentric compressive force induces a hogging moment in the chord to counteract the sagging moment due to the load from a purlin at the midspan of the chord (Figure 13).

P.F. Pleshkov is referred to in *Wooden Structures*. His work on timber spaced columns during the period 1930–40 is cited in *The Structural Use of Timber* (Booth & Reece 1967). They refer to a paper written in 1952, so clearly there was some transfer of the results of Soviet research to the West.

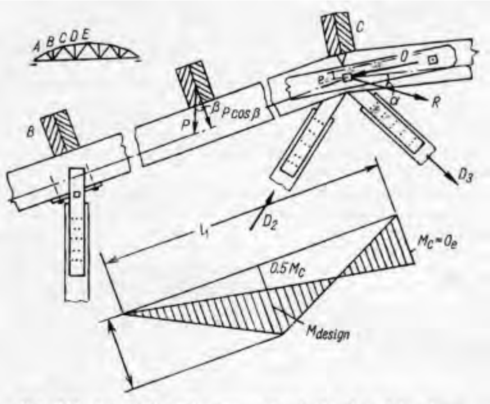


Fig. 143. Calculating the upper chord of a bowstring truss

Figure 13. Eccentricity induced hogging moment.

Vladimir Shukhov, who was and is well-known outside Russia, does not get a mention in the index of *Wooden Structures* although his lattice towers are described. It is a feature of the book and of Soviet engineering generally that individuals are given credit for their particular inventions and contributions (e.g. Kalashnikov).

William Louis Goodman was the translator of *Wooden Structures* into English. The success of the book owes much to his appointment. Goodman had translated and had published editions of many famous Russian writers such as Prishvin (*The Lake and the Woods*), Gogol (*The Inspector General*) and Chekhov (*The Cherry Orchard*) since the late 1940s. He was also familiar with the language of timber having himself written *Woodwork from the Stone Age to Do-it-Yourself* (1962), *The History of Woodworking Tools* (1964) and *British Plane Makers from 1700* (1968). Translating a 638-page, highly technical book is no mean feat and there are many intelligent footnotes by the translator. Mir Publishers were aware of the importance of the translation since they asked for opinions on the translation and design at the back of the book.

8 GLUED-LAMINATED, CROSS-LAMINATED AND DOWELLED-LAMINATED TIMBER

Glulam beams solve several engineering and aesthetic problems. They use thin laminations so depth and width of the beam can be varied. With finger-jointing, the length of the beam is not dictated by the available length of timber. The beams can be bent before gluing to create arches – timber is turned into an almost plastic material. Glulam beams and columns are an attractive alternative to steel and concrete with some sustainability credentials. Out of glulam came cross-laminated timber, which is in effect slabs of plywood on a large scale primarily for use as floors. CLT is capable of spanning in two directions and uses a vast amount of glue. dowelled-laminated timber, the latest development, is a welcome step away from the use of glue – horizontal dowels hold together vertical strips of timber to create one-way spanning slabs; it is like a wide vertically laminated beam.

The use of glue has problems. It requires careful handling and protection of the workers during production. When the beams and slabs become redundant they will, if burned, give off toxic fumes, which will contribute to global warming. Many other engineered timber components such as plywood, MDF, OSB etc. use glue – the total quantities must be enormous. All these products have a primary energy content much higher than sawn timber, for plywood seven times higher (Blass et al. 1995). Glue is a product of the petrochemical industry with a questionable future.

The downside of the use of glue is being appreciated. The European Union currently has a research program *Towards Adhesive-Free Timber Buildings* led by the University of Liverpool. They aim to eliminate adhesives and steel, and have designed and built a small office building in 2020 using only timber. The dowels are made from densified softwoods rather than oak.

9 CONCLUSIONS

Wooden Structures, like other classics such as Tredgold, is a fascinating example of the engineering approach in one country at a particular time. Mukhanov in *Design of Metal Structures* advances the idea that a Soviet school of designing steel structures was created in the 1930s. *Wooden Structures* is evidence for the possible existence of a Soviet school of designing timber structures. But it would be ill-advised to assume that based upon an English translation of this one book. What is needed is a search through the archives in Russia and a survey of the surviving timber structures from the era, which could best (and probably only) be done by a Russian.

The Derevyagin beam, despite its limitations, shows that it is possible to construct a built-up timber beam without glue.

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Open session: Building machines, tools and equipment

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The tools of the Roman stone craftsman: The marks left on marble decorative elements in Valeria

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ABSTRACT: The last archaeological excavations in the Hispano-Roman city of Valeria (Cuenca), have made it possible to exhume the remains of a monumental thermal complex. The building was ornamented with paving and wall mosaics and an elaborate marble decorative program. After its abandonment, the building was not subjected to an intense plundering. This has enabled recovering much of the marble elements composing the internal decoration of cold rooms. The total number of fragments exceeds 6000 pieces. The specific study of these pieces has consisted of the visual analysis of each one, registering their detailed description in a file where all the notable characteristics are also collected. This information has revealed the presence in many of them of various marks, traces and strokes that offer us information about the type of tools used by the Roman craftsman during the process of making the marble elements and the technical function that these tools had.

1 INTRODUCTION

The Hispano-Roman city of Valeria is located in the central part of the interior of the Iberian Peninsula. Founded in 92 BC by Gaius Valerius Flaccus, proconsul of Hispania Citerior and to whom it owes its Latin name (Gozalbes 2009), the city enjoyed from the end of the 1st century BC a privileged legal status, as is cited in some classical sources (Plinio, *NH*, III.25). This circumstance, together with its strategic location on a passage route from the Mediterranean coast to the interior of the peninsula, must have played a very important role in the economic and political growth that the city experienced at the beginning of the 1st century AD and which had one of its most notable reflections in the monumentalization of urban public spaces.

From 2014 to 2019, various archaeological interventions have allowed the exhumation of part of the structures corresponding to a thermal complex of monumental dimensions. So far, three interior rooms and one external space have been identified. The latter clearly porticoed, so it could probably function as *palaestra* or open space for gymnastic activities.

The interior rooms correspond to a *natatio* or indoor cold-water pool located at the western end of the building, which has direct communication with a central hall paved with large slabs of marble in pinkish and white tones, placed in such a way that each slab contrasts chromatically with its adjacent. At the eastern end, there is a large room paved with a complex mosaic that stands out for the polychrome geometric patterns that configure the general composition of the design used (Atienza 2019).

Figure 1. View of the upper room of the *frigidarium* with the access stairs in the foreground and the remains of the pavement mosaic in the central part of the room.

This last room is accessed through a staircase with four steps, so its level of transit with respect to the rest of the rooms is raised (Figure 1).

Throughout all the excavation campaigns carried out in the area, a collection of marble fragments made up of about 6000 pieces has been recovered, and which could reach 8000 units with the inclusion of the elements recovered in the last archaeological excavation, whose analysis is being developed at the time of this writing.

With regard to the origin of the marbles, the detailed study carried out on this type of elements has determined that they belong to more than a dozen different typological varieties and come from quarries located in different parts of the Roman Empire (Atienza, in press).

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All these pieces were worked by one or several specialized artisans, the *marmorarii,* using different tools depending on the type of piece and its functionality within the decorative program (Calabi 1961; Susini 1966).

2 TYPOLOGY OF TOOLS

The detailed study of recovered stone elements from *Valeria* has made it possible to establish a first conclusion: about 60% of the studied pieces have some type of marks, holes or visible traces.

Moreover, these marks were made on the stone pieces at different times of the decorative process of the thermal complex, with different purposes in each case and also using tools and different for each case.

Taking precisely this diversity into account, the marks identified have been grouped as corresponding to four different types of tools:

- cutting tools
- carving tools
- tools for marking incised lines
- drill.

2.1 *Cutting tools*

2.1.1 *The saw*

The division of the large blocks extracted in the quarries into other smaller pieces used to be carried out through the use of saws, whether these were operated by manual means, animal traction or even by means of mechanical devices activated by the action of the water (Kessener 2012). The archaeological remains of some stone block sawmills that were still in operation in Late Antiquity, such as those of Ephesus (Mangartz 2007), Gerasa (Seigne 2007) or Hierapolis of Phrygia (Grewe 2010; Grewe & Kessener 2007), indicate that the saw blades could reach a length close to two meters. Although archaeological remains have not proven their existence, it is probably that stonemasons from Roman times used saws of a smaller size, easily manageable and transportable, for sawing soft or medium-hard stones.

The saw blades could be toothed, all identical to those used in woodworking, in the case of soft rocks such as limestone and sandstone (Atienza 2010, 2019).

For cutting hard stones such as marble or granite, the saw blades had a straight edge. Some counterweights exerted pressure on the blades, and these, in turn, moved over silica dust that acted as an abrasive, which was, in effect, the cutting agent. The use of abrasive powder was always accompanied by the use of water to facilitate the movement of the saw and also to avoid excessive heating of the metal sheet.

Within all the pieces of Valeria that are part of this study, regardless of the role they had in the decorative program, more than half have marks of sawing. The cutting marks consist always of a series of parallel grooves, more or less close to each other, depending on the hardness of the rock and the pressure on the cutting blades (Figures 2, 3).

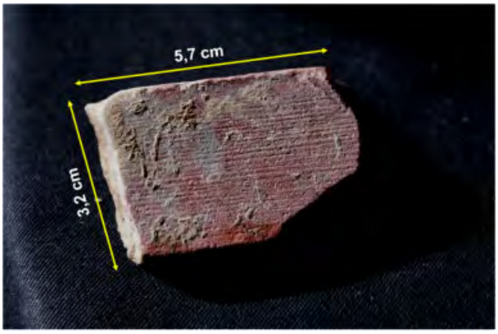

Figure 2. View of the back of a small decorative cornice. The surface is completely covered with traces of sawing, slightly marked and very close to each other.

Figure 3. View of the back surface of a cladding ballast (*crusta*) covered by sawing traces. Note how, unlike the previous image, the grooves are more marked and separated from each other.

Figure 4. Examples of large-format marble decorative cornices on the back side of which the distal end breakage caused by saw cutting is observed.

Sometimes failures have been detected in the cutting process, as the saw blade deflects and causes warping and loss of flatness of the surfaces.

In many of the examples observed, the saw does not go through the entire thickness of the part, but instead the cut stops a few millimeters from the edge. This procedure allows separation of the cut piece easily, preserving the integrity of the visible edges. This way of cutting causes a characteristic mark in the pieces in the form of a narrow and longitudinal fracture with a rough appearance that runs through the entire piece. This imprint, in the case of cornices or molded pieces, is always located on the back face, that is, the one that was hidden from view once it was placed in its final position (Figure 4).

Figure 5. Various types of carving tools used in the process of making stone elements in Roman times: 1. flat chisels; 2. round chisel; 3. tooth chisel; 4. channeling chisel.

2.2 *Carving tools*

A significant number of the pieces studied (about 40%) has on their surfaces markings which may be due to the use of specific tools used during the process of making and carving of the stone elements (Figure 5).

2.2.1 *Flat chisel*

A significant number of the pieces (about 40%) studied has on its surface markings may be due to the use of specific tools used during the process of making and carving of the stone elements.

The most numerous correspond to those produced by the use of the *scalprum* or flat chisel in the phase of regularization and refining of the surfaces. The chisel is one of the most versatile tools used in stonework due to the number of functions it can perform and its use is widely attested in all the phases that make up the stone working process (Bessac 1987; Rockwell 1993; Susini 1967). Essentially, the instrument comprises an elongate body of a generally circular section, whose effective end has a beveled or wedge shape.

Marks of the chisel have been found in practically all kinds of functional elements, but they are especially evident in the wall revetment slabs and flooring slabs. In many of these pieces, the traces of the chisel are preserved perfectly visible on the perimeter faces, because usually the backside retains traces of sawing or roughing aspect, and on the front face the process of final polishing has removed the chisel marks (Figures 6, 7).

Figure 6. Fragment of parietal revetment slab on whose perimeter face traces of the use of the flat chisel are preserved during the regularization of the surface. The circle marks the place where the marks can be seen.

Figure 7. Decorative cornice fragment with flat chisel marks on one of its surfaces. This surface was not visible when the piece occupied its original place in the building's decorative program.

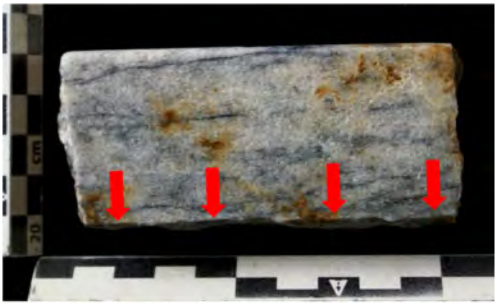

Figure 8. Piece of wall revetment showing flat chisel strokes on one of the perimeter faces. These hits have been made in an aligned manner and have fractured part of the surface. The top image shows a view from the front; the bottom image shows an image from the back.

The use of the flat chisel as a roughing tool has been documented both in wall and paving slabs, as well as in some molded pieces. Both in the wall or flooring slabs the chisel has been used on the perimeter faces to fracture the surfaces by a snap (or a series of strokes) and reduce the contact surfaces between adjacent pieces. This procedure was especially important to facilitate the process of placing the revetment pieces on their support (Figure 8).

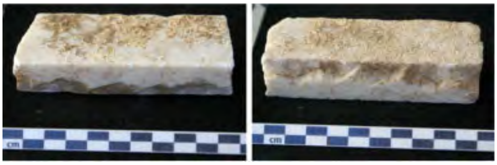

Figure 9. Thin molded marble piece whose thickness has been delimited by aligned chisel strokes. Arrows indicate where the chisel edge struck.

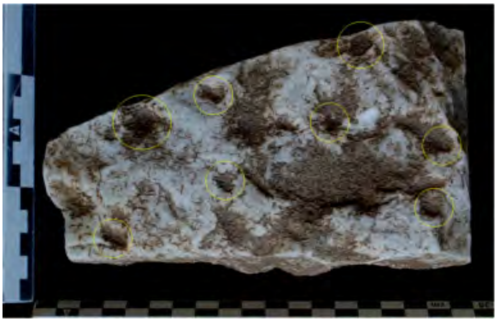

Figure 10. Bottom face of a rough-look pavement slab that has been pointer worked. The circles indicate the points where the tool has struck.

For some molded elements, simple but very numerous in the total set of pieces, the strokes of the chisel have caused the complete fracture of the piece in such a way that it limited the thickness that it should have (Figure 9).

2.2.2 *The point chisel*

The point chisel is a manual tool. The body consists of a metal shaft, generally cylindrical section, whose active end terminates in pyramidal or conical shape. It is usually used in roughing operations where it is necessary to remove a lot of material to get closer to the final shape of the piece or, also, when you want to give a rough appearance to a surface (Rockwell 1993).

The effect of this tool on the stone causes a stippled carving that can adopt a regular distribution, in the form of straight or curved grooves, or an irregular distribution (Bessac 1987; Rockwell 1989, 1990, 1993) where the blows are distributed randomly over the surface (Figures 10, 11).

In some pieces from Valeria, especially decorative cornices, the use of the pointer has been detected for the carving of notches and grooves for the adjustment of metallic fastening elements (Figure 12).

2.2.3 *The tooth chisel*

This tool is in all its characteristics similar to the straight chisel. The difference between the two tools is that the latter has a toothed cutting edge (Bessac 1987).

The number of teeth the tool has depends on the width of the cutting edge. Usually find these tools are found with a number of teeth ranging between three and five, although it is possible to have two-teeth tools and up to a maximum of seven (Rockwell 1989, 1990, 1993; Susini 1966).

Figure 11. View of the back face of a parietal slab that has been worked with a pointer and that has left marks in the form of elongated grooves arranged in a regular manner over the entire surface.

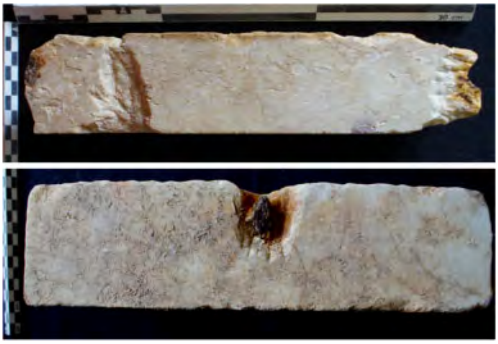

Figure 12. Examples of decorative cornices with carved notches on their upper face. The work of these recesses has been carried out with a pointer, whose marks are noticeable on the surface.

Figure 13. Marble decorative piece with toothed chisel marks in a carved cavity on one of the perimeter faces.

In many cases it is not easy to distinguish the marks left by the tooth chisel from those other marks left by the point chisel (Bessac 1988, 1993). In the case of the toothed chisel, the grooves left in the rock surface are always parallel to each other and above all always have the same depth.

Of all the pieces studied, only one of them shows clear traces of the use of this type of tool. It is a fragment of lesene that presents on one of the perimeter faces a carved cavity whose surface shows the typical traces of this type of tool (Figure 13).

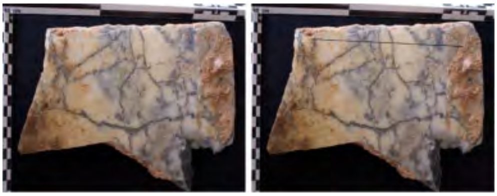

Figure 14. Parietal revetment slab with an isolated rectilinear incised line that runs along the entire surface. In the right image it is highlighted with a dark line the location of the incision.

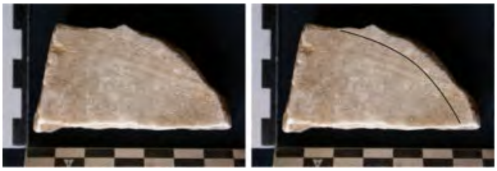

Figure 15. Parietal revetment slab with an isolated curvilinear incision line running across the entire surface. In the image to the right, the location of the incision is highlighted with a dark line.

2.3 *Tools for carving incised lines.*

2.3.1 *Tracer*

Although it is not a well-known aspect, the drawing on a stone support was very frequent (Inglese & Pizzo 2014; Ruiz de la Rosa 2016), and not only for the layout of large structures, but also for the design of minor details in a piece of small dimensions.

About 10% of the pieces studied present some type of trace or incision on their surface. These are very thin lines that can appear isolated or related to other lines, and adopt both a rectilinear and a curvilinear path (Figures 14, 15).

This type of incised lines has been observed in all kinds of elements, regardless of the functionality that they had in the overall composition of the decorative program (Inglese & Pizzo 2014).

These lines were made with a tracer (*subula*), which would consist of a thin, metal rod with one of its ends sharpened. In most cases, they used to have the purpose of serving as indicator elements to the different operators who participated in the process of carving and placement (Atienza 2017).

In the case of some molded elements that have been part of this study, the decoration design was made directly on the surface of the piece, before proceeding to its carving. These designs were made by incisions which served as reference for the final drawing of the decorative motif (Figure 16).

It is quite possible that, in the case of curvilinear incised lines, these were made directly with a compass (*circinus*) provided with sharp metal ends (Atienza 2010). Use of this instrument is present in many artistic representations of Roman times.

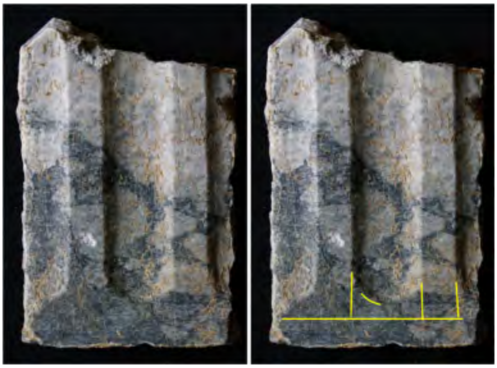

Figure 16. Lower fragment of a fluted lesene in which are preserved some incised lines which by their situation and disposition, may have been part of the original design of decoration.

In the case of straight lines, normally they were drawn with the help of simple wooden slats, if they were simple lines, or with squares, when it came to drawing right angles.

2.4 *The drill*

The drill or trephine (*terebra*) was a very versatile tool used in the work of the stone craftsman for various functions. The usual way of using the drill during Roman times was pulling back and forth by belt or cord, as it is represented in some artistic manifestations of this period.

The mechanism consisted of two independent pieces: on the one hand, a cylindrical wooden shaft and, on the other, a drill or metal head. The shaft had a slot or hole where the drill was fitted. The drill bit should have a sharp or pointed distal end to facilitate penetration into the stone material (Bessac 1987; Blagg 1976; Rockwell 1993).

The shaft-drill system was rotated by wrapping a band or string around it and alternately pulling the ends back and forth. At the same time as the shaft turned, the operator should press on the shaft. So that this tool could be operated by a single person, the ends of the string were tied to the ends of a bow, which was operated with one hand, regulating the turning speed, while the free hand was responsible for position the shaft at the precise point and exert the necessary pressure.

The drill holes in the pieces analyzed in this study range from 2 to 5 cm in length and 0.4 to 0.6 cm in diameter.

In the pieces analyzed, the main function of the drill was to make holes in which to insert the fixing elements of the pieces to their wall support. Therefore, the elements most often have drill holes are cornices and slabs of parietal coating (Figures 17, 18).

Finally, the use of the drill as an auxiliary element to the carving of decorative motifs in high relief has also been detected. In cases where delicate details had to

Figure 17. Wall revetment decorative slab with a drill hole for the insertion of the fixation pin. The fracture of the piece has sectioned the hole.

Figure 18. Upper face of a large-format decorative cornice with two drill holes that were used to install the fixing system of this element to the supporting wall.

Figure 19. Fragment of decorative relief with traces of the drill being used to perform delicate details.

be sculpted and where it was not possible or practical to use another type of tool, the use of the drill allowed the making of holes or grooves that created the desired depth appearance (Figure 19).

3 CONCLUSIONS

It is enough to observe the extensive scientific bibliography that, in the last decade, has been published on multiple aspects that refer to the decorative theme during Roman times to realize that much progress has been made in the knowledge of this matter.

Aspects such as construction techniques, the use of certain materials or commodities trading at regional and interregional level have been discussed in many forums and scientific meetings that have generated a vast knowledge on these issues.

However, in the field of construction in Roman times, there are still aspects that, with few exceptions, remain without being studied in depth and detail. One of these aspects is that of stonework in general. Its monuments are known and admired; their sculptures are appreciated; the bases, columns and capitals of its constructions cause us surprise and wonder. But we have barely managed to know how these elements were made, by whom, and what techniques and tools they used.

Manually, stonework has almost disappeared from professional practice and there are fewer and fewer craftsmen using traditional techniques in the manufacture of its products.

But despite the fact that the panorama is not optimal, many of the works that have survived from Antiquity retain the marks of the tools that made them possible.

The careful study of these marks and traces informs us of the techniques and tools used, of the knowledge that the builders had about the materials used in the construction and decoration of their buildings and also of the transmission of knowledge and ideas from one place to another.

Archeology has recovered a multitude of tools used in stonework from Roman times and therefore we know their shape. Artistic and documentary sources give us information on the role and uses that each of these tools had. But the direct study of the marks and traces shows us that many of them did not have a single predetermined function, but were very versatile and, therefore, capable of being used in very varied tasks, depending on the needs and expertise of each artisan.

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An innovative flooring technique in Roman times (Villa of Diomedes, Pompeii)

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ABSTRACT: In Pompeii, the study of the Villa of Diomedes (2012–2020) revealed a concrete horizontal floor with a corresponding highly original coffered ceiling. A few rare examples of this type are preserved in other Roman sites, although no other examples have been identified in the cities of Vesuvius at the current stage of research. This concrete floor and its terraced roofing were built during one of the final stages of construction of the Villa of Diomedes, just after the large earthquake that hit Pompeii in 62/63 AD. The ingenuity of the system lies in both its masonry structure and coffering decoration, which would have permitted its rapid completion while other work quickly ensued to restore the numerous damaged elements of the villa. This innovation has the particular feature of being executed in the urgency of post-seismic reconstruction.

1 INTRODUCTION

1.1 *The Villa of Diomedes*

Located 200 m from the Porta Ercolano and bordered by the *Via delle Tombe*, the Villa of Diomedes is one of the most emblematic edifices of Pompeii. Since 2012, a multidisciplinary program has aimed to reconstruct its entire evolution from the material construction of a Roman villa to its contemporary imaginary representation, resulting in the publication of a monograph in 2020 (Dessales 2020a).

This monument presents various exceptional characteristics. Firstly, the villa was one of the first buildings excavated in Pompeii between 1771 and 1775. The head of excavations, Francesco La Vega, a military engineer in the service of King Charles of Bourbon, produced highly detailed reports and drawings, all of which constitute a remarkable corpus of documentation. Secondly, the excellent state of preservation of the villa and its proximity to the northern entrance of Pompeii, where the coaches of the rare and privileged visitors stationed in the late 18th century, made it one of the most described and illustrated monuments of the Grand Tour in Italy. Thirdly, the monument was the result of one of largest building processes in Pompeii: originally set out on four levels, the building spread over more than 3700 square meters with a panoramic view of the Gulf of Naples opposite the island of Capri.

By applying archaeology of construction methods, the individual techniques used for the erection of the building and its decoration were identified to uncover the different construction and reconstruction stages of the villa (Dessales 2016). A specific analysis of the elevations, openings and floors was carried out (De Martino et al. 2020; Dessales 2020b; Letellier-Taillefer 2020). The study of the standing remains, without the initiation of new excavations, was combined with archival research which sometimes revealed elements that have since been eroded or disappeared completely.

1.2 *Typology of the floors*

The archaeological evidence distinguishes two types of floors and ceilings: firstly, wooden structures with horizontal floors (as an intermediate level or terrace) and sloping roofs; secondly, concrete structures with masonry vaults and a unique example of a masonry floor, as we will see (Figure 1).

Wooden floors can be identified by observing the rectangular or circular holes cut into the walls to accommodate the beams or joists that were leaning against them (Adam 2005: 402; De Martino 2020; Ruggieri 2017; Ulrich 1996). Above, a conglomerate slab was made of wood or masonry concrete and a finishing coat of *cocciopesto* (lime mortar with crushed terracotta) or mosaic flooring constituted the top layer (full thickness 15 to 40 cm). Without considering the sloping roofs, at least six areas in the Villa of Diomede had a wooden floor (four branches of portico N°. 63, rooms N°. 66 and 73).

Differing on account of their static nature and thrusting system, concrete vaults are characterized by the use of rubble or terracotta masonry bonded with mortar. Centering allows the realization of this monolithic structure: once the setting is complete,

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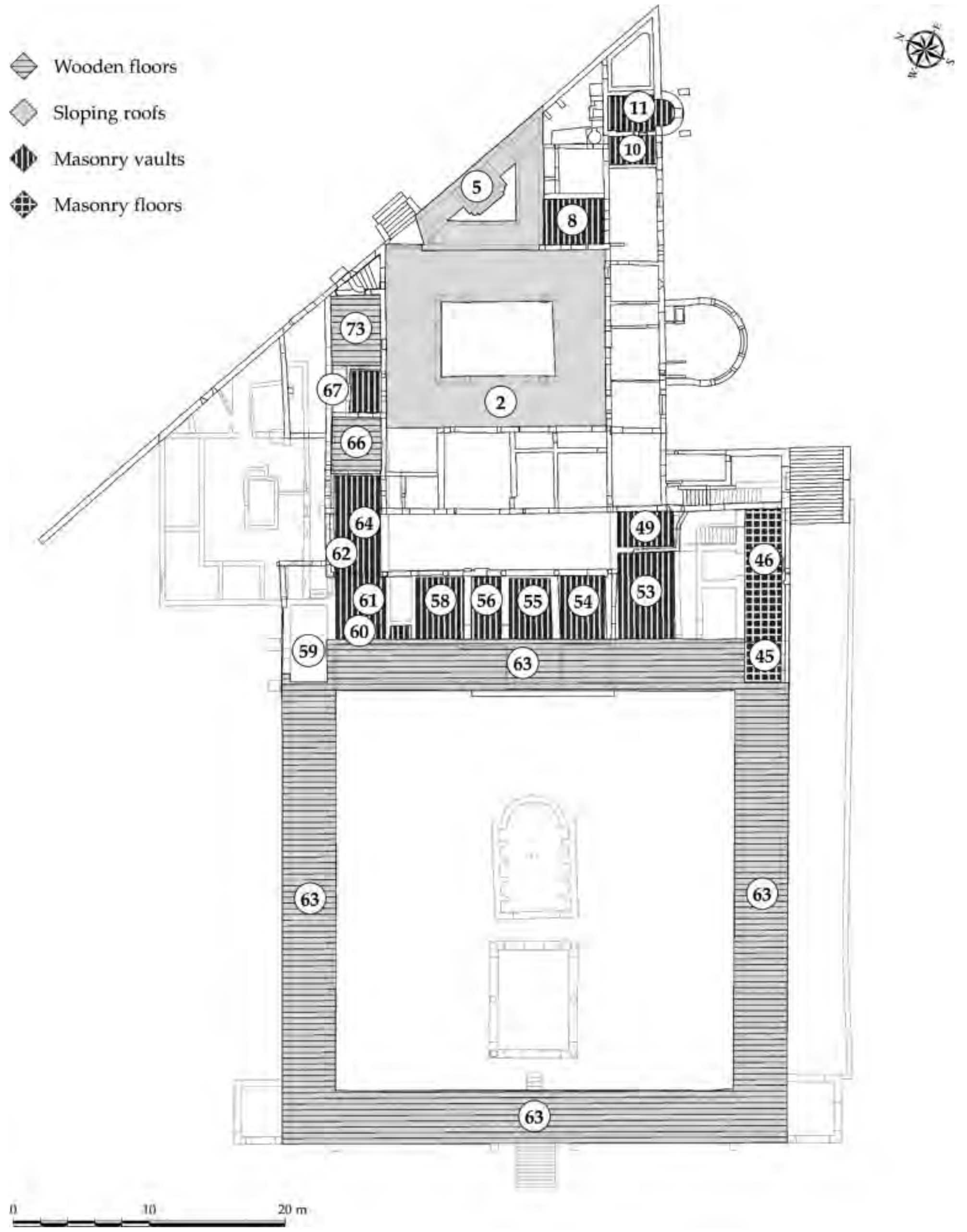

Figure 1. Plan of the Villa of Diomedes, with the archaeological evidence of the identified types of floors (Julien Cavero).

the wood coffering of the centering is taken away (Adam 2005: 326; Giuliani 2015: 130–137; Lancaster 2005: 21–50; Lugli 1957: 668). Its imprint can be observed in various barrel vaults of the villa. The surface of the intrados was regularized by a finishing coat in plaster or decorative stucco. A layer of masonry and a finishing coat were applied to the extrados to allow people to walk above it on an upper floor or terrace (full thickness at crown 40 to 110 cm: De Martino et al. 2020). Fifteen rooms in the Villa of Diomedes are still covered by a barrel vault (N°. 8, 10, 11, 49, 54, 55, 56, 58, 60, 61, 62, 64 and the three branches of cryptoporticus under portico N°. 63) in variable conditions of preservation, with some even retaining their painted decoration.

A unique floor structure characterized areas N°. 45 and 46, which initially corresponded to a single space that connected the reception rooms to the south portico N°. 63: a horizontal masonry floor (Figures 2, 3), which we will be detailed in the following pages.

Figure 2. Orthophotograph of the concrete floor in area N°. 46, internal view (Thomas Crognier 2015).

Figure 3. View from the east of gallery N°. 45 with its concrete floor; in the foreground with the arch buttress built in 1774 (Hélène Dessales 2011).

2 CONCRETE FLOOR TECHNIQUE

2.1 *Standing remains*

Now quite degraded, the structure is only visible in fragments along the entire length – 12.70 m – of this 2.73-metre-wide gallery. It is relatively well preserved in the covering of area N°. 45 over a length of 2.60 m between arches 443 and 444. These are two of the four buttress arches raised during the 1774 excavation to consolidate the structure, as explained in the excavation diaries: "(…) e dai fabbricatori si è lavorato a rinforzare con nuove mura le fabbriche antiche, particolarmente una volta a cassetoni, che merita dell'attenzione per la sua novità …" ["(…) and the builders have worked to reinforce the old work with new walls, particularly a coffered vault, which deserves attention for its novel design (…)"] (Fiorelli 1960: 276).At the time of its discovery, the excavators described it as a coffered vault and observed its exceptional character, which they wanted to preserve Iron bars were fitted in the 1930s to ensure the stability of the remains (Figure 3) (Dessales 2020a: 86–87).Two of the five rows of coffers are still intact. A stucco cornice of 4 cm width that covers the joint between the ceiling and walls is still partly in place in the east, north, and south (Figures 4, 5); in the west, it disappears at the level of the modern buttress arch.

Its good state of preservation allows us to observe the stratigraphy of the concretes and mortars and thus partially reconstruct the construction process of this ceiling, which is highly original in terms of both its structure and decoration (Figure 4), as noted on numerous occasions by the travelling architects of the 19th century (F. Mazois, H. Parke, G.A. Blouet, F. Duban, P.F. Fontaine: cf. http://villadiomede.huma-num.fr/bdd/images/, ID. N° 20318, 20265, 20002, 20013, 20720).

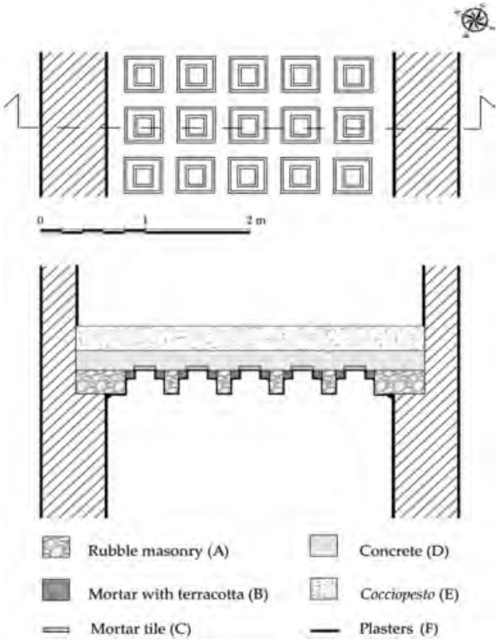

Figure 4. Map and section of the concrete floor in area N°. 46 (Hélène Dessales).

2.2 *Morphology of the floor*

This continuous floor in unreinforced concrete spans over 2.73 m; the north and south load-bearing walls have a thickness of 0.60 m (Figure 4). The total thickness of the floor is around 60 cm, which takes into account all the constitutive elements of this slab and its decorative coatings, from the perimetrical stucco cornice to the ground-level floor, an open-air gallery situated above portico N°. 63. The square coffers 36 cm in length are placed in rows of five and spaced 14 cm apart. With a depth of 15 cm, they have two vertical planes each with a height of 7.5 cm and a projection of 8.5 cm: the 36 cm length at the opening reduces to 19 cm at the back of the coffer (Figures 2, 5). No trace of a beam is visible in the thickness of the floor, whose entire section is clearly visible due to its collapse on the west side; the assembly is therefore exclusively made of concrete. The technique uses a formwork system with successive layers of concrete and mortar. Despite the infeasibility of completely "dissecting" the floor and the uncertainties surrounding the various modern restorations, a hypothetical reconstruction is still possible.

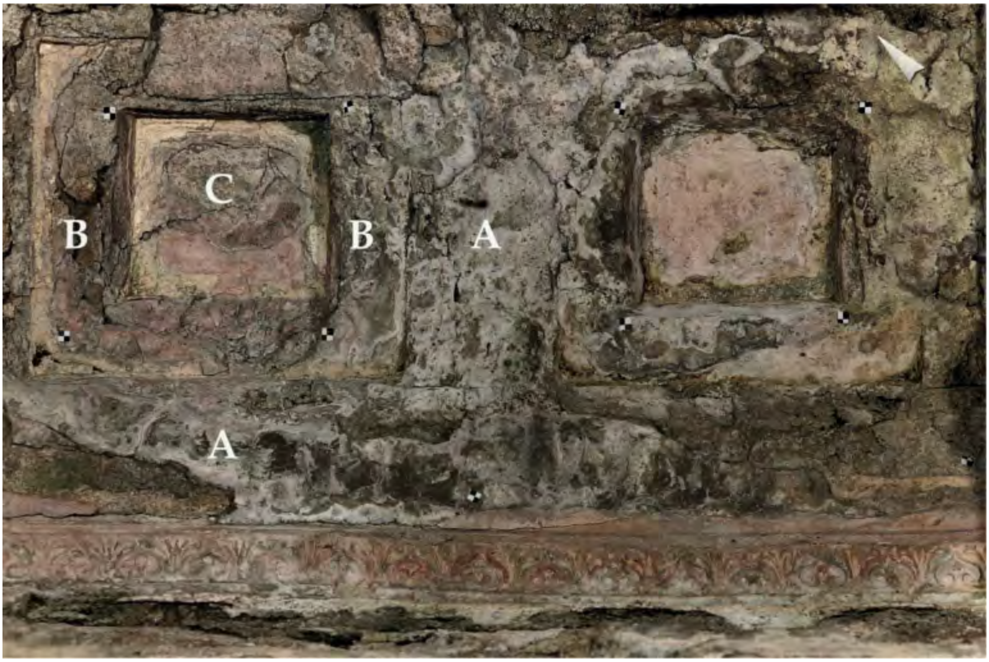

Figure 5. Detail of the cornice and two coffers with their well-preserved plaster decoration (area 45) (Thomas Crognier 2015).

2.3 *Reconstruction of the building stages*

After the layout of a scaffold, the first stage involved the installation of a temporary platform of timber beams. The beams did not lean against the walls, as no mortice joint is visible – although we cannot exclude the possibility that these holes were filled in antiquity or during the restorations – but they were instead supported by props resting on the floor.

The masons then positioned the wooden formwork, probably along the entire width of the gallery and in several lines of coffers (Figure 6). A special formwork was made for each coffer, whose configuration can be reconstructed. Four planks, around 6 cm in height, were placed vertically to create a 36-centimetre frame (i.e. the dimension of the lower part of the coffer), while the fifth was placed flat. On this “overturned crate”, four other planks, 9 to 10 cm in height, were placed vertically to produce a second frame of similar dimensions. On the temporary platform, these formworks created a hollow grid with a depth of around 15 cm, which was filled with small blocks (10 cm on average) of local limestone and cruma, a very porous volcanic rock chosen for its lightness, and then covered with several layers of a lime and coarse sand mortar (Figures 4, 5A). To facilitate the work during these diverse operations, the builders probably progressed from east to west in rows of 2 × 5 coffers by placing them in pairs from the lateral walls to the center. The upper part was then removed from above.

A second formwork was placed in the center (Figure 7). To create the volume of the coffers, these two formworks were perhaps installed at the same time, with their elements being partly fixed together (possibly with nails). This second formwork was constituted of four vertical planks with a height of 6 cm to create a 19-cm frame (i.e. the dimension of the upper part of the coffers), while a fifth plank was placed flat above them. To create the top of the moulds, the peripheral empty area was filled with the same type of mortar containing a large aggregate that includes fragments of crushed terracotta with a maximum granular size of 3 cm (Figures 4, 5B). The moulds were then covered by a 2-centimetre layer of grey mortar with lime and finer sand to create the mortar (not terracotta) tile 19 cm in length (Figures 4, 5C), which can be observed at the back of several coffers (Figure 6). On the existing remains, we can identify dilatation joints that attest to the successive layers and usage of formworks (Figures 5, 6).

More concrete was then poured, probably in several continuous strata, to obtain a thickness of around 20 cm (Figures 4, 5D). Finally, the layer of terracotta concrete was laid, forming the floor of the ground-floor gallery (Figures 4, 5E).

After the removal of the entire formwork from below, the painters and plasterers finalized the decoration of the ceiling with a painted stucco cornice to highlight the corner of the coffers and the joint between the ceiling and the walls (Figures 4, 5F). There is no evidence of any product used to remove the formwork (sand, dirt, etc.). Likewise, there is no trace of the formwork beams.

Figure 6. Detail of a coffer with a mortar (without terracotta) “tile” (Hélène Dessales 2015).

As the final stage, the walls were painted with a very similar decoration but in a different polychrome rendering in the two areas N°. 45 and 46.

The fundamental question raised by this floor – unique in Pompeii at the current stage of research – relates to its stability. The resistance of the structure is ensured by the mass effect of the concrete. The total weight of the slab is reduced by the presence of coffers (depth 15 cm), which create a volume of empty space. The total thickness of the slab (60 cm) seems adapted to the span (2.73 m), with the solid load-bearing walls (60 cm) guaranteeing the total stability. This also signifies that the flooring of the garden galleries (Figure 1, N°. 63) was made using another technique, as the pillars could not have supported such a weight, most likely placed on wooden beams, the traces of which are still discernible in the south and north walls of the portico.

Area N°. 59 in a symmetrical position does not seem to have received the same type of covering. The ceiling is flat and plastered with a motif of colored stars on a white background (Dessales 2020a: 50–2, 378). The floor structure is difficult to observe and is most likely a wood joist floor, as in portico N°. 63, whose ceiling has not been preserved and can be supposed to be identical to that of area N°. 59. As we will see below, the coverings of areas N°. 59 and 45–46 were made in different phases. In area N°. 59, it results from the third building stage of the villa in the years 40–50 AD (Dessales 2020a: 354–55), whereas in area N°. 45–46 in a sector impacted by seismic disturbances, it was rebuilt during the successive stage after the 62/63 AD earthquake (Dessales 2020a: 389–390, Pl. XLI).

3 AN INNOVATION IN CONTEXT

3.1 *Examples of similar structures*

A few rare examples of such concrete floors are preserved in Roman architecture. These floors are sometimes defined as flat concrete vaults (*volta piatta* or *piana*). In the case of the Villa of Diomedes, the excavation reports from 1773 use the term for a structure that is now absent in area N^{o}. 76 (Fiorelli 1960: 272). No other examples have been identified in the cities of Vesuvius at the current stage of research. A reasonably similar floor is found in the Forum of Caesar in Rome in the roof of a shop with a width of around 3 m; devoid of coffers, the flooring is made of concrete with an aggregate of pumice stone and volcanic dregs (Amici 1991: 54, 162). Dated to around 45 BC, this structure is one of the first examples of the use of pumice stone in roofing.

In the Tripartite Building at the Villa Adriana, which is an emblematic laboratory of architectural experimentation in Roman times, a very peculiar and innovative flat concrete covering was identified; it was build up in portions cast in formworks, resting on a support of wooden beams (Amici 2016), a characteristic which differs completely from the Pompeian case.

A later example is found in the Severan substructures of the Palatine, where the flat concrete vaults with a 35-centimetre thickness are only supported by stone cornices on the side (Middleton 1892: vol. 1, 70–72, Figure 64). Other similar cases can be cited in the *Horrea Agrippiana* and *Casa di Giulo Romano* in Rome (Parker 1968–69; Bauer & Pronti 1978: 133), as well as in ancient Ostia (Amici 1991: 163). As in the case of the Villa of Diomedes, these are always spaces of reduced width where the floor span is limited.

3.2 *Coffering decoration*

In the case of Pompeii, the specificity of this ceiling covering lies in the presence of caissons on the ceiling. A dozen barrel vaults with stuccoed coffering are preserved in Pompeii, mainly in thermal contexts (Barbet, pers. comm.). In a dwelling, one of the most remarkable examples is in a room of the *Casa degli Amorini Dorati* (VI 16, 7/38) (Barbet 2009: 219–21, Figure 154). The layout of caissons in masonry barrel vaults is a well-attested device in Roman Italy, as early as the late 2nd century BC (Temple of Fortune in Praeneste – Adam 2005: 372, Figure 435; Barbet in prep.). The concrete is moulded on a centering in which the outline of the coffers had been prepared.

Appropriate formworks in wood or bricks placed on the centering are able to receive the moulded decoration of the coffering (Giulian 2015: 128, Figure 42.6; Lancaster 2005: 45–6; Lugli 1957: 668, 677–79, Figure 144, Pl. CCIX). In the case of our reconstruction of this building process in the Villa of Diomedes, we favor the use of a rather rudimentary system of cut planks, improvised from readily available materials (Figures 6, 7), as the local production of moulded architectural terracotta was very limited in the Vesuvian area (Dessales 2016).

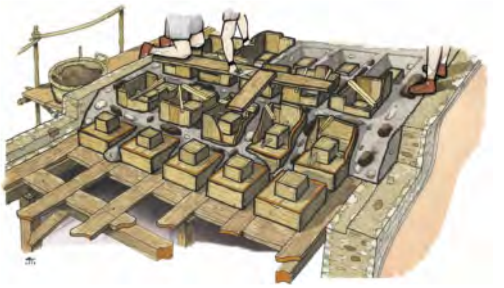

Figure 7. Reconstruction of the floor's construction system (area 45: formwork system (Antoine Louis).

Inspired by Roman architecture, of which the Pantheon is one of the most emblematic examples with the coffered intrados of its dome, Italian Renaissance treatises provide interesting technical details of the layout of coffers built with the conglomerate vault (Belli 2017; Pagliara 2017: 62–65). In the *Re aedificatori*a (VII.11), Alberti precisely describes a construction system for a coffered vault based on his personal experience. This consists of placing heaps of mud bricks evenly on the arch to produce the hollow shape of the coffers. They are removed once the vault is dry, thus creating the desired relief of the coffers (Alberti 1988: 222). Regarding other evidence, Vasari begins his introduction to architecture in the fourth chapter of *The Live*s by focusing on the "*volte di getto intagliat*e" ["concretional vaults with incisions"] as the best example of modern technical skills (Belli 2017: 80; Vasari 1878: 13–140). He describes wooden boxes placed on the centering planks, which correspond to the voids of the caissons, after covering the whole with the conglomerate of the vault. He credits Giuliano da Sangallo with reviving this "antique manner".

Returning to the case of the Villa of Diomedes, this concrete floor thus seems to reproduce a technique that was well distributed and adapted to the coffered barrel vaults. However, the horizontal layout of the structure can also refer to a coffered ceiling with painted wood, a beautiful example of which was recently uncovered at Herculaneum, in the *Casa del Rilievo di Telefo* (Ins. or. I 3), built during the Augustan period and restored several times before 79 AD (Figure 8) (Camardo & Notomista 2015), or to a coffered ceiling made of carved and painted stone, as in the famous Tomb of Elahbel at Palmyra, which was completed in 103 AD (Galinowski 1970).

4 CONCLUSION

In this Pompeiian *unicum*, the ingenuity of the system lies in its capacity to combine both structure and decoration, which would have permitted the rapid completion of the ceiling, while other works quickly ensued to restore the damaged parts of the villa (Dessales 2020a: 425). In fact, the ceiling and its terraced roofing

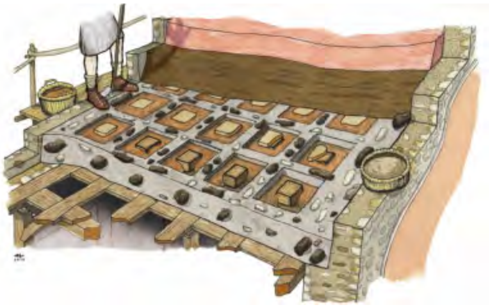

Figure 8. Reconstruction of the floor's construction system (area 45): covering by successive layers (Antoine Louis).

would have probably been reconstructed just after the devastating earthquake of 62/63 AD (Savino 2009).

During this final stage of the villa, the owners were able to quickly restore the building, which was affected by another seismic tremor shortly before 79 AD and still in the midst of reconstruction work at the time of the eruption of Vesuvius. The upkeep and uniformity of the coatings would have been a greater priority than the finesse of the decorations given the large size of this villa.

The creation of this floor can therefore be considered to be a post-seismic innovation in the context of an emergency architecture. It reveals technological transfers, mixing the layout of conglomerate coffered vaults and the imitation of painted wood ceilings, and is a good example of the "vaulting technique in context" (Lancaster 2015). Further investigations would be worthwhile to identify other examples of this type in Pompeii, although the structural fragility of the device – partly collapsed in the Villa of Diomedes – perhaps explains the absence of other archaeological evidence.

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How to build a (brick) barrel vault

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ABSTRACT: The present paper discusses several difficulties associated with the erection of barrel vaults. Although it may seem rather straightforward to build a barrel vault, the task gets increasingly difficult as thickness of the vault and height above ground increase. This is particularly true for barrel vaults constructed in brick, the standard material of most early modern vaults. With the difficulties and possible remedies in mind, the paper attempts a reassessment of the sources concerning the most important monumental early modern brick barrel vaults; namely, those of St. Peter's Basilica, Rome.

1 DIFFICULTIES IN BARREL VAULT ERECTION

At first sight, it appears quite straightforward to build a barrel vault. All you need is a set of centers (ribs) of semi-circular shape, installed at reasonable distances from each other, and battens or boards to form the lagging. Then, the individual courses of masonry can be laid, the centering eased after a reasonable time, and the vault will stand if appropriately dimensioned.

However, the greater the span of the vault and the higher the vault is above ground, the more difficult the vault erection gets. Essentially, vault thickness increases proportionally to the span, meaning a cubic increase in volume and weight. This requires adequately dimensioned supports for the centering, which has to carry the weight of the barrel vault until the keystone is set in. A greater vaulted space is generally also higher above ground, making the erection of the supporting structures still more demanding.

The problem of vault thickness and weight can be alleviated to some extent by coffering. However, coffering adds complications to the erection procedure. Either the coffers have to be defined by appropriate negative forms on top of the lagging, or they have to be built in suitable bond with regular stones.

All the problems described were faced by architects of the Italian Renaissance. From the very beginning of the early Renaissance in Florence, coffered barrel vaults played a key role in evoking the association of “classical” Roman precedents. Notable examples include the porch of the Pazzi Chapel in Florence, the narthex of the sacristy of the Santo Spirito, Florence, and the narthex of Madonna dell'Umiltà, Pistoia – all in precious ashlar construction and of limited span. However, following the precedent of Leon Battista Alberti, who designed monumental barrel vaults for Sant'Andrea in Mantua, large-span barrel vaults soon became one of the characteristic features of Renaissance architecture. These wide-span early modern barrel vaults are typically built in brick rather than ashlar or the Roman *opus caementicium.* For example, the 18.60-meter span of the nave of Sant'Andrea which was executed by Luca Fancelli (around 1485–1500, i.e. after Alberti's death) is a brick structure, as are the impressive barrel vaults above the naves of the Milanese churches of Santa Maria presso San Satiro, Santa Maria presso San Celso, and San Vittore al Corpo, to mention some well-known examples. The most famous of all, of course, are the barrel vaults of St. Peter's Basilica, Rome, and for them, a rich iconographic tradition exists. Notably, Vasari's famous fresco in the *Sala dei Cento Giorni* in the palace of the *Cancelleria*, Rome, painted in 1546, shows the vaulting of the southern arm under the supervision of Antonio da Sangallo the Younger (Figure 1). These brick vaults are approximately 2.75 m thick and span no less than 23 m (Bellini 2001: vol. 1, 104). Vasari later repeated the fresco almost identically in 1555–63 in the *Sala di Leone X* in the Palazzo Vecchio, Florence.

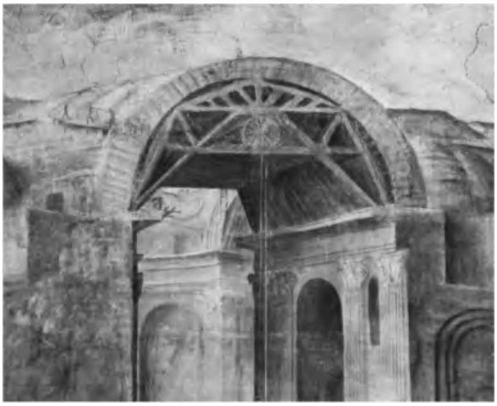

Figure 1. Vasari's fresco (detail) of 1546 in the *Sala dei Cento Giorni*, Cancelleria, Rome, showing the erection of the brick barrel vault on the southern arm of St. Peter's Basilica, Rome (author).

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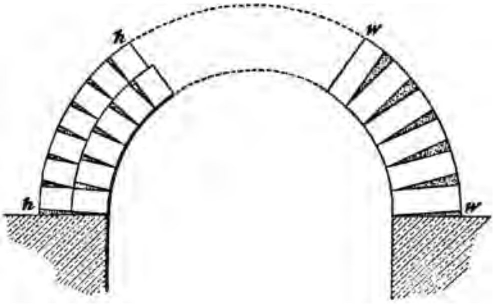

Figure 2. Brick arch built in rings (left) or with thick wedge-shaped joints (right) (Fidler 1875: vol. 1, 29).

Building a barrel vault in brick entails further problems: either one employs special wedge-shaped voussoir bricks, or one uses standard rectangular ones. While custom-made wedge-shaped bricks are a reasonable solution in the case of small-scale arches and barrel vaults, they are much less useful for large vaults: with a large radius, the wedge angle gets so small that workers on site have difficulty identifying the narrow side of the brick, meaning that the wedge bricks may easily be set the wrong way. Furthermore, barrel vaults whose thickness exceeds the length of a single brick call for different sets of wedge-shaped bricks. For vaults as wide and thick as the barrel vaults of St. Peter's in Rome, for example, the use of special wedge-shaped bricks is therefore entirely impractical.

On the other hand, if normal rectangular bricks are to be used instead of wedge-shaped voussoirs, the mortar joints should be wedge-shaped. While wedge-shaped joints (possibly guaranteed by the insertion of small fragments of stone on the wider side) are once again a viable technique for small-scale vaults, they also become problematic when the vault is very thick (Figure 2). Classical mason's rules call for vault construction in perfect bond throughout the thickness, as confirmed, for example, by the 19th-century standard textbook *Routine de l'établissement des voûtes* by Dejardin (Dejardin 1845, 261). However, bonding through the thickness inevitably leads to unacceptably thick mortar joints in the case of very thick barrel vaults built with rectangular bricks. The alternative strategy of vaulting in concentric rings – practised particularly in English tunnel and bridge construction in the 19th century (Figure 2, left), such as at the famous Wharncliffe Viaduct (1836) of Brunel's Great Western Railway – is also a partially dissatisfying solution since it easily leads to debonding of the inner ring, and successive progressive collapse of the entire vault, even though vaulting in rings offers the apparent advantage that the innermost rings may serve as additional "centering" for the subsequent ones, implying the applicability of less robust supporting structures.

Figure 3. Example of an arch with parallel rather than radial brick courses caused by uniform mortar joints, resulting in an irregular wedge-shaped closure (Bologna, Santo Stefano; author).

Figure 4. Example of a "badly built" brick arch (Baldinucci 1682: unnumbered plate).

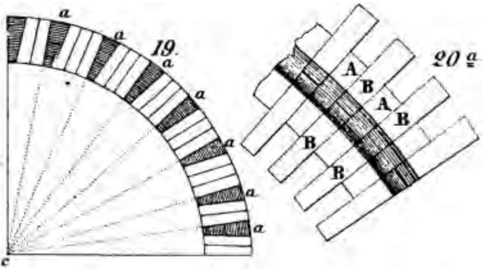

Figure 5. Insertion of wedge-shaped bricks at regular intervals between normal bricks (Wolfram 1833: plate II, detail).

In bricklaying practice, joints typically tend to assume uniform thickness, inevitably resulting in parallel rather than radially oriented courses of bricks (Figure 3). Historic builders and architects were well aware of this problem (for an impressive if slightly exaggerated drawing, see, for instance, Koller 1800: plate L; for a general discussion of non-radial joints resulting in phenomena termed "*Ueberwölben*" and "*Unterwölben*", see Meerwein 1802: 3–4). The issue was typically tackled by inserting wedge-shaped pieces of irregular masonry to adjust the orientation of the joints at those locations where the deviation from radial courses became intolerably high (Figure 4). Another alternative is the ad hoc production of pronouncedly wedge-shaped bricks on site by manual adjustment of ordinary bricks; these strongly wedge-shaped pieces are then inserted into the arch at certain intervals, rather than employing wedge-shaped bricks throughout (Figure 5, wedges marked a). This is the standard technique suggested by 19th-century German textbooks for avoiding irregular courses of bricks (Gernrath 1825: vol. 1, 149; Weiss 1820: vol. 1, 126; Wolfram 1833: 19).

2 STANDARD AND NON-STANDARD TECHNIQUES OF CENTERING

Beyond bond, centering is another major issue in barrel vault construction. While more complex vault types may partially rely on free-hand erection, the typical bond of barrel vaults with courses of stones running parallel to the axis of the vault requires full lagging and full support until the whole vault is keyed.

Pictorial sources on the centers used for barrel vault erection are scarce. At the end of the present contribution, we will reassess the centers employed at St. Peter's, Rome (Figure 1). However, these centers may not represent standard technology of their day.

Fortunately, another important 16th-century source permits fantastic insight into the contemporary technology of centering; namely, the letters and drawings by Galeazzo Alessi concerning the construction of the basilica of Santa Maria di Carignano, Genoa. Alessi, being one of the busiest architects of his day, visited that construction site only at irregular intervals, directing most of the works remotely by letters and sketches. This superb body of sources has been conserved and made accessible by the editions of Santo Varni (Varni 1877) and, more recently, Andrea Ghia (Ghia 1999). Specifically, in a letter dated 30 November 1560, Alessi instructs the local worksite supervisor on how to construct the centers for the barrel vaults: "The vault should *not* be built the normal way, since that will cost twice as much and be of great hindrance. Such centers will even be less solid than the *new* centering which I have explained in detail to master Bernardino, the local supervisor, and which is shown in the enclosed sketch. This type of centering perhaps not being known in Genoa; I have furthermore contacted master Bernardo Spazio, who confirms to have seen such a vault construction elsewhere, and offers his help if required, although I am confident it will not be needed." (Varni 1877, 14–15). What Alessi meant with the "normal way" of constructing the centering is evident from the accompanying sketch (Figure 6).

The sketch shows the "normal centering" on the right and the "extraordinary centering" on the left. We will presently return to discussing the "extraordinary centering". For the moment, we will concentrate on the "normal centering" (Figure 6, right). It rests on a massive timber framework reaching from the floor level up to the vault. More specifically, it rests on a central post from which struts radiate like the branches of a tree to support the centers. Apart from these struts, the principal structure of the centering frame resembles a roof truss with two rafters and a tiebeam.

Indeed, sources from other projects indicate that this kind of ground-supported centering was the standard solution for the erection of major barrel vaults and other vaults as well. It was even commonly used for ribbed vaults, as witnessed by Vincenzo Scamozzi who had the opportunity in 1600 to visit the worksite for the re-construction of the vaults of the cathedral at Langres which had been destroyed by a fire in 1562. Scamozzi quite unambiguously describes the centering as being supported by a well-executed timber frame resting on three parallel rows of enormous squared timber posts – two at the walls and a middle one – and stabilized by diagonal wind-bracing – each post reaching "*da piano terra fino sotto la volta*" ("from the ground floor to below the vault") (Scamozzi 1615: vol. 2, 346).

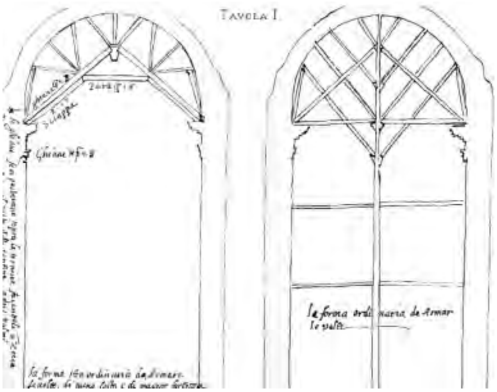

Figure 6. Alessi's drawings explaining barrel vault erection in Santa Maria di Carignano, Genoa (Varni 1877: plate I).

The scarce archival evidence on vault erection suggests that the centering seen by Scamozzi was not an exception but rather the rule, as confirmed by Alessi. Figure 7, for example, shows a design drawing for the erection of salt depot in Rouen, 1720. The timber structure corresponds in detail to the centering described more than a century earlier by Scamozzi. Unlike Alessi's "normal centering", it does not rely on a projecting cornice as a support, but rests on posts aligned with the lateral walls like the one described by Scamozzi. Evidently, the centering is made up of squared timber and employs classical carpentry joints. Soulaces provide sufficient wind bracing. The heavy load of the voussoirs is carried by a lagging consisting of full beams rather than thin boards. As late as 1820, this kind of centering was planned for the construction of an innovative shipyard in Toulon (N.N. 1825: vol. 2, n^{o}. 110).

Perhaps Fancelli's centering for Sant'Andrea in Mantua had already used a similar structure. In any case, the barrel vault of that church was built in three successive sections, a procedure which was probably related to the required re-use of a costly ground-supported centering (cf. sources edited by Gaye 1839: 295–296 and 324–325).

On the other hand, Alessi's "extraordinary centering" (Figure 6, left) is not supported from the ground but rests exclusively on the cornice. Furthermore, its roof-like truss lacks a tiebeam. It relies exclusively on a pair of principal rafters connected to each other at

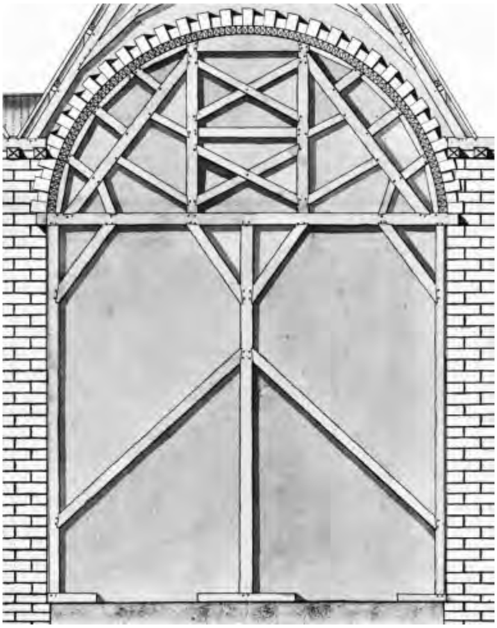

Figure 7. Design of the centering for building a barrel-vaulted salt depot at Rouen, 1720 (Bibliothèque Nationale de France, Paris; detail).

their top ends by a little hanging post. Evidently, such a truss must have been much more difficult to erect than one resting on the ground. This explains why Alessi would have recommended Bernardo Spazio's help if at all needed.

Unless the span is too large, a more conventional centering held together by a tiebeam may be lifted from the ground as an entire preassembled structure. When the truss is sufficiently stable in itself and the supporting cornices or corbels are strong enough, a preassembled centering may work even without additional direct support from the ground.

Indeed, unsupported centerings were not an invention of Alessi. Rather, they were already a recurrent topic in the Sangallo family around 1500. At any rate, the Uffizi collection holds several sketches (attributed to Antonio da Sangallo the Elder) which show such centers. GDSU 7807 A, for example, represents two designs for free-span centers which are evidently derived from typical Italian queen- and kingpost roof trusses. These designs are obviously targeted at relatively large spans (particularly the queenpost truss) and heavy vaults (indicated by ashlar voussoirs on the drawings). Carpenters who were able to erect roof trusses over large spans could also have erected the closely related centers.

Other designs from Antonio da Sangallo the Elder's sketchbooks appear more demanding since they dispose of the tiebeam. Figure 8 shows an example (others include GDSU 7808 A v., GDSU 7811 A r.). Perhaps both Antonio and his elder brother Giuliano had ample opportunity to experiment with such centers when they built their famous churches at Prato (Santa Maria delle Carceri), Montepulciano (Madonna di San Biagio), and elsewhere. At any rate, Giuliano included a sketch of a very similar centering in his small sketchbook *Taccuino Senese* (fol. 27 r., see Falb 1899). These technicians of the late *Quattrocento* paved the way for the constructive solutions applied under the direction of their nephew Antonio da Sangallo the Younger at new St. Peter's, Rome.

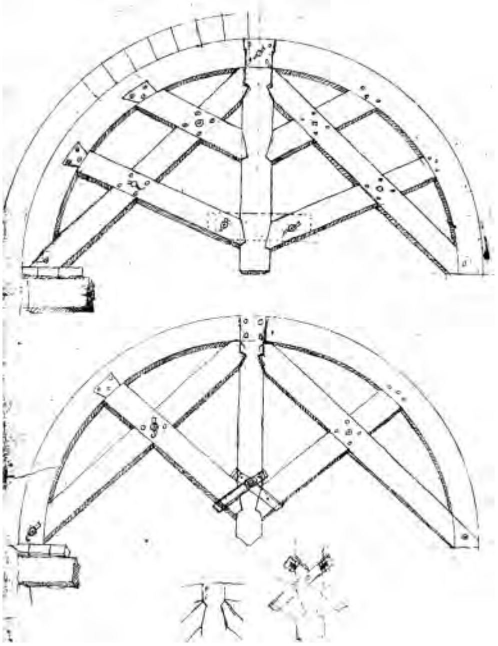

Figure 8. Sketches attributed to Antonio da Sangallo the Elder, undated, showing free-spanning centers for a barrel vault (Florence, Uffizi, GDSU 7837 A).

3 THE SPECIAL CASE OF ST. PETER'S

When Antonio da Sangallo the Younger conducted the construction of new St. Peter's, the standard technology for building heavy barrel vaults relied on ground-supported centers which were similar to the ones already discussed. For example, the heavy coffered *volta a rosoni* below the future *Ottagono di San Simone Mago* was erected on a conventional centering, as documented by the famous anonymous drawing Ashby 329 (ca.1525) in the Vatican Library. However, this was a barrel vault of limited span, moderately high above ground. By contrast, the four large arches connecting Bramante's central pillars under the future dome were far too high to be reasonably supported from ground. Moreover, their 23-metre span practically precluded the use of a continuous tiebeam. A good alternative to the standard procedure was therefore a key requirement.

It must have been a fortunate coincidence that Bramante's "chief engineer", Antonio da Sangallo, was

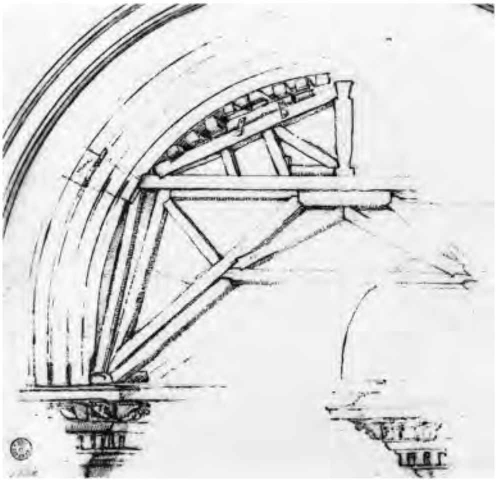

Figure 9. Sketch attributed to Bramante showing the centering for the principal arches of St. Peter's (Florence, Uffizi GDSU 226 A; detail).

in charge of execution when these arches were actually built in 1510. Obviously, the established expertise of the Sangallo clan was now ultimately bearing fruit. Although the famous sketch concerning the construction method is commonly attributed to Bramante himself (Figure 9), it is very likely that the idea came from one of the three Sangallos, particularly if one takes into account that not a single other technical sketch from Bramante's hand has survived and that, being a painter by education, he was evidently not much interested in technical detail at all. Even the technique of representation in "pseudo-perspective" is similar to the Sangallo drawings in the Uffizi.

The centering shown follows the same constructive principles as the designs of the elder Sangallos: ideas derived from traditional roof truss design are suitably combined to adapt the center truss to the shape of the arch. However, there is no tiebeam at the base of the truss. Rather, the roof-like truss filling the upper part of the cross-section is strengthened from below by a structure that resembles the system of a free-span timber bridge. The two cornices serve as abutments for this bridge.

In this case, the sheer size of the center definitely precluded lifting as a whole, but suggested assembly of the individual parts directly *in situ*. It is certainly not by coincidence that "*2 fondamenti grandi, fatti nella tribuna grande per armare*" ("two large bases, made under the big formwork centering structure") (cited after Frommel 1976: 128) had to be built first, probably in order to support the huge pole-cranes for the assembly of the centers.

The Uffizi sketch GDSU 226 is worth a further close examination: contrary to what Metternich and Thoenes (Wolff Metternich 1987: 193) considered spuriously as "*ad hoc* patchwork executed by the carpenters", the small wedges shown at some of the joints are nothing other than preparations for de-centering: easing these wedges, it would be possible to take out some of the struts of the structure, ultimately making it possible to strike the entire centering.

Another detail concerns the masonry of the arch itself. Approximately in the middle of the arch, a large voussoir-shaped part of the masonry is explicitly denoted as "*pietra*", i.e., stone (illegible in the reproduction of Figure 9). There has been a lot of guessing about the purpose of these isolated stone voussoirs. According to C. L. Frommel (1994: 610) these ashlar pieces were intended "*come punti di riferimento per gli stuccatori*" ("as a reference for the plasterers"). However, keeping in mind that the arches were built exclusively or at least mostly in brick (a definitive classification is not possible since the four principal arches are now embedded into the cylindrical plinth below Michelangelo's dome), it becomes evident that the principal objective of inserting the ashlar wedges was in reality to periodically readjust the joints of the brick apparatus to radial directions – an issue of major structural importance in such a huge brick arch.

The so-called Bramante drawing GDSU 226 A or the corresponding real structure was documented in a singularly large number of further 16th-century drawings and other pictorial records. A fairly comprehensive list of these may be found in Bernd Kulawik's thesis on the drawings contained in the "Destailleur D sketchbook" (Berlin, Kunstbibliothek; see Kulawik 2002, 807–825).

However, it must be noted that not all of these drawings refer to the four principal arches supporting the dome. The centers used for the barrel vaults of the four principal arms of the Basilica made use of the same principle, probably until the very completion of the nave under Carlo Maderno in 1613. This is also evident from Vasari's famous fresco of 1546, which shows the vaulting of the southern arm, known as the Cappella del Re di Francia (Figure 1).

The different places where the centers were used explain the slight differences in dimensions and construction, in contrast to Kulawik's hypothesis that some of the drawings were "design drawings", while others could be qualified as "surveys of the centerings in place" (Kulawik 2002: loc. cit.). Some of the drawings such as Destailleur D, fol. 112 r. (Figure 10) include a lot of detailed dimensions and indicate very clearly the carpentry joints used. Evidently, the whole construction was conceived from the very beginning to allow easy disassembly at the end (no treenails employed).

Vasari's fresco provides another very interesting detail: the centers are extremely densely spaced. In the painting, they seem to be almost contiguous. This matches well with archival records stating that Antonio da Sangallo the Younger employed no less than 14 centers for the short western arm in 1543, resulting in an axial distance of only 1.25 m between the individual trusses (Bellini 2011: vol. 1, 104). The same archival source also hints at the use of 110 full-size beams (*arcareccie*) employed as lagging. Both details correspond to the very thick and therefore very heavy vault.

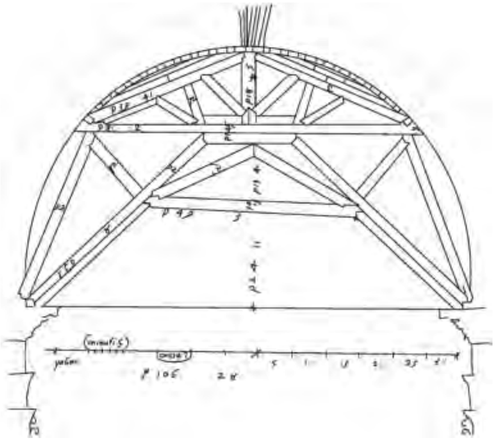

Figure 10. Representation of the centers for St. Peter's in the Destailleur D codex (Kunstbibliothek Berlin, HDZ 4151, fol. 112 r., redrawn by author).

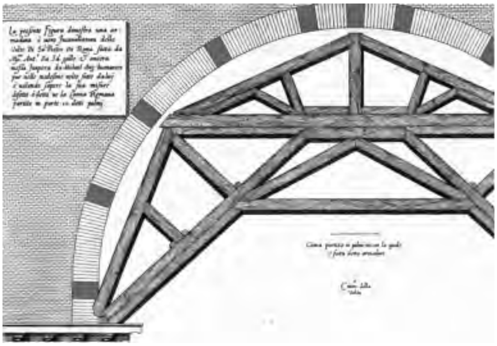

Figure 11. Engraving of Jacob Bos (1561) showing the centering of the northern arm of St. Peter's, Rome (detail; modified by author with grey shading of ashlar voussoirs).

One further detail of Vasari's fresco cannot be explained so easily: there is a lifting device standing on the collar beams of the centering. At first sight, it is not clear what this device at that particular location could have been useful for: being located below the lagging, it could not easily have assisted the transport of the bricks. However, the solution of this enigma may be quite straightforward: the first third of the vault on both sides could have been built with almost no support from the centering. This corresponds roughly to the level of the collar beam. Only at that moment might the erection of the centering have been required. From that point onwards, lagging might have been laid onto the centers incrementally, following the progress of the bricklaying. That way, the crane might have been very helpful indeed.

The centering of St. Peter's is probably best known neither from Vasari's frescoes nor from the various drawings in the archives, but rather from an engraving by Jacob Bos published in 1561 as part of Antonio Lafreri's collection *Speculum Romanae Magnificentiae* (Figure 11). The legend at top left indicates that the figure shows the centering employed in 1549 to build the barrel vault of the "*Cappella dell'Imperatore*", the northern arm of the cathedral, now under Michelangelo's direction.

The engraving shows a very similar structure as the other sources. Even the wedges holding the struts in place until the time of de-centering are present. Furthermore, the engraving once again indicates that the brick arch is interrupted at various locations by ashlar voussoir blocks reaching through the whole thickness of the vault (emphasized in Figure 11 with grey shading). The relatively dense sequence of these blocks underlines their role as means of ensuring radial joint orientation. Incidentally, this technical device was once again copied by Alessi in Santa Maria di Carignano. On 11 May 1561, Alessi indicated to the local worksite supervisor how to execute the brick masonry of the principal barrel vault: "It must be at least 5 palmi [1.11 m] thick; for greater safety, I wish that a voussoir made of hard rock should be inserted into the masonry at intervals of 6 palmi, binding together the whole thickness like a wedge." (cited after Ghia 1999: 363). It is rather unlikely that the close correspondence between the procedures followed at St. Peter's and in Alessi's project is a pure coincidence. Rather, it is highly probable that Alessi was inspired not only by the Greek cross plan of Bramante but also transferred technical detail directly.

4 COFFERING

Finally, execution of the coffering is worth consideration. In the case of St. Peter's, the procedure followed was recorded by Vasari (Vasari 1568: vol. 1, 27): The coffers were formed by hollow wooden chests set up on top the lagging. Vasari provides a lot of somewhat confusing detail about how the raw decoration of the coffers was also produced directly during vault construction rather than by later stuccowork: the profiles framing the coffers were inserted into the formwork; in order to reproduce these detailed shapes, the formwork was then covered with a layer of fine mortar before the brick voussoir stones were laid. Vasari's passage has occasionally given rise to misinterpretations, reaching as far as to claim that the vaults were built in a sort of concrete (Marconi 2004, 193; Wolff Metternich 1987, 193). However, Vasari's description is unequivocal and has been interpreted correctly by other authors (Maclehouse 1907: 86; Pagliara 1998–99: 251). In any case, the barrel vaults of the four principal arms of the church are certainly not in concrete but brick, leaving possible doubts only concerning the principal arches under the dome itself, if any.

Using brick, however, coffers may be produced in an alternative way too. Once again, Galeazzo Alessi is a key reference in this respect. Considering the coffering of the vaults at Genoa, he wrote on November 30, 1560: "The formwork has to be made as smooth and contiguous as possible, for I want to draw on it all the squares and octagons of the cofferings which will receive the roses. For I intend to save the cost and effort which would be required to construct the second formwork […]. In order to achieve that, I intend to fill the coffers with bricks set without mortar inside the shapes drawn with carbon on the lagging, corresponding to the desired shapes of the coffers, as will be indicated in due time to the workers. This way, the coffers will be formed, and when the centers will be eased, the said bricks will drop out and leave the square and octagonal hollows as desired" (Varni 1877: 15).

This description echoes very closely a passage in Leon Battista Alberti's treatise where he describes a very similar technique to create the coffers in a brick barrel vault: "I have made them in a simple and cheap way: For I drew the shape of the future coffers directly on the lagging, namely the required squares, hexagons and octagons. Those parts which I desired to be hollowed out were filled with crude bricks set in mud in place of mortar. These hills on top of the formwork were then included in brickwork diligently laid with lime mortar, paying attention to properly bonding the thinner and the more massive parts. When the centering was eased, I could easily take out the provisional bricks, leaving the coffers exactly as desired". (Alberti 1512: fol. CIX v.–CX r.). This description leaves no doubts whatsoever about the process. Nonetheless, it has once again been misinterpreted as a record of constructing a barrel vault in a sort of concrete (Gargiani 2003: 222; uncritically followed by Schlimme 2010). In fact, the very detail about "proper bond" between the massive and more delicate parts would suffice to remove all uncertainties about how to interpret the passage. Once again, the similarities between Alberti's description and Alessi's method are too close to assume pure coincidence.

Alberti's text is generally associated with the actual coffered barrel vault of the androne of Palazzo Venezia, Rome (Fig. 12). Inspection of that vault suggests that indeed it is built with "*mezzane*" (or "half bricks"). The coffers are rather imprecisely executed, which one could expect when filling them temporarily with soft mud bricks during vaulting, the bricklayers' only guide being the drawings on the surface of the lagging.

However, the dislocated coffers have certainly not shifted horizontally during the pouring of some "concrete" as assumed by Gargiani (2003) and Schlimme (2010). It would also have been rather difficult to secure the mud bricks on the lagging in such a way as to enable the subsequent pouring of concrete (Figure 12).

5 CONCLUSION

The erection of the large principal arches and barrel vaults at new St. Peter's marks a crucial point in the development of early modern vaulting techniques. There was no direct precedent for brick barrel vaults of this size. In the vaults built in St. Peter's, the accumulated experience and knowledge of the 15th century was finally realized. The technical advances achieved at St. Peter's, however, did not impact decisively onto the following developments – quite on the contrary, rather straightforward ground-supported centerings continued to dominate the scene. Only occasionally – notably in Galeazzo Alessi's Santa Maria di Carignano in Genoa – did later architects try to continue the ideas of St. Peter's not only architecturally but also technically. From the currently available archival and printed record it even appears that Alessi's project was the only one to resume the ideas of the classical period of Renaissance. Outside Italy, no trace has thus far been identified that would testify to further spread of the construction technology experimented at St. Peter's during the first half of the 16th century.

Figure 12. Palazzo Venezia, Rome. Coffered brick barrel vault of the vestibule (author). Note dislocated coffers shifted laterally with respect to the row below.

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Quicker, cheaper, higher: A “new” French scaffolding system in the first half of the 20th century

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ABSTRACT: In 1894, a French patent for a wood frame scaffolding system using prefabricated ladders was registered in the name of the engineer Jules Funcke. Unlike the many quickly forgotten scaffolding patents registered at the time, this particular system begun to be used by a wood merchant called Hector Lièvre at the beginning of the 20th century. It was then widely used until the 1970s. This wood scaffolding system called “*Échafaudages rapides*” enabled the building of really huge structures reaching impressive heights for the time. This historical enquiry is based on analysis of a corpus of postcards, patents, catalogue and newspaper articles documenting this system. Using this wide range of sources complemented by a further reading in the light of historiography, this paper proposes some reflections on the technical device itself and on its innovative characteristics. It also demonstrates that the notion of innovation is a complex issue with its threads interwoven across interconnected layers.

1 INTRODUCTION

1.1 *A new lacy scaffolding system*

In December 1904, a strange construction started to climb the façade of the Trinity Church in the ninth arrondissement of Paris (Figure 1). The church was being covered up with scaffolding, which in itself was not out of the ordinary as city buildings and monument are frequently under repair. However, this particular scaffolding labelled “*Échafaudages rapides, Hector Lièvre*” was quite a new sight with its gossamer appearance a consequence of a new building system using ladders. The quickness of its set-up also attracted attention as it took only a few days of assembly to reach the impressive height of 64 meters contrary to the considerable time usually needed to build heavier carpentry scaffolds. Another alleged novelty was the fact that it could reach this considerable height with the minimum anchorage on the building unlike the putlog scaffolding system in use at the time.

1.2 *A historical enquiry*

This event may have been one of the first French occurrences of this new scaffolding system which then entered use until the 1970s.

This discovery, made in the course of PhD thesis research work, has triggered a complex enquiry through several fields of knowledge ranging from Construction History to Visual Studies. Though often leading to dead ends, it did also bring to light some useful material.

This paper aims to summarise this investigation into scaffolding technology and proclaimed innovation by cross-referencing data obtained from iconography, technical knowledge and historiography. It will rely upon the analysis and interpretation of the material found in the course of the current PhD thesis, namely a corpus of postcards, patents, catalogues, invoices and newspaper articles. These will be read in the light of a historiographical range of works coming from available sources from a French language perspective—mainly French and English publications, and in terms of geography, thus works accessible in academic French libraries or online (see specific references). Their analysis, completed by a technical reading of construction processes, unveils the presence of several recurring lines of thought. They can be used as a grid to propose some reflections on the technical device itself and on its innovative characteristics.

2 HECTOR LIÈVRE, SELF-PROCLAIMED INVENTOR

In 1909 and 1913, Hector Lièvre (1859–1922), a Parisian timber merchant reconverted into the scaffolding trade, registered two versions of a patent for a device covering scaffolding and buildings under construction. The covering device described in the patents, called an umbrella, was based on a specific scaffolding system using ladders, a system previously patented by someone else. Hector Lièvre was the enterprising and successful business owner of a company named *Échafaudages Rapides.* And he also had a definite talent for advertising and staging what he presented as a real innovation in the field of scaffolding construction. In 1911, at the International Exhibition of Industries and Labour in Turin, he was awarded a prize in the Public Works category for this same scaffolding system

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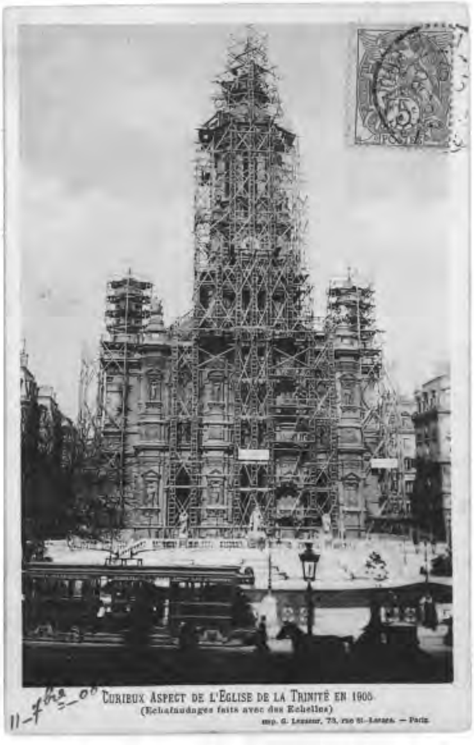

Figure 1. A 1905 postcard featuring the Trinity Church in Paris under scaffolding. “Curious aspect of the Trinity Church in 1905 (scaffolding made with ladders)”.

presented as his invention. He also released a lot of advertising postcards featuring buildings under scaffolding (Figures 2, 7). Thirty-one of them are included in the corpus here. His advertising talents also seem to have extended to the semantic field. Even if this system was used by other companies in the following years—a catalogue from another company, Boillot, used the term *Échafaudages Rapides* in the 1930s, the name may well have been invented by Hector Lièvre. There is no mention of it before he set up his company. There is a rather strong sense of self-statement in naming one’s company *Échafaudage Rapide* when your surname is Lièvre, knowing that *rapide* and *Lièvre* are respectively the French for *rapid* and *hare*. A company called *Rapid Scaffolding* set up by *Mr Hare* seems like a kind of joke but also seems like a very good advertising idea.

Whether due to his sense of self-promotion or really as his invention, the idea that this scaffolding system was a Lièvre innovation seems to have been sufficiently effective to bring Jean-Baptiste Ache (1905–1983), construction teacher at the Conservatoire National des Arts et Métiers, to write in 1955 that “quite late in the 19th century, the companies in charge of solving the problems of building sites sought economic solutions through the standardisation of scaffolding elements; moreover, industrial sawing and the generalized use of bolts facilitated this trend. The so-called ‘Rapid’ wooden scaffolding marked the development of this trend. This system of grooved ladders and diagonal tie, due to Hector Lièvre, is very well known” (Ache & Poupée 1955).

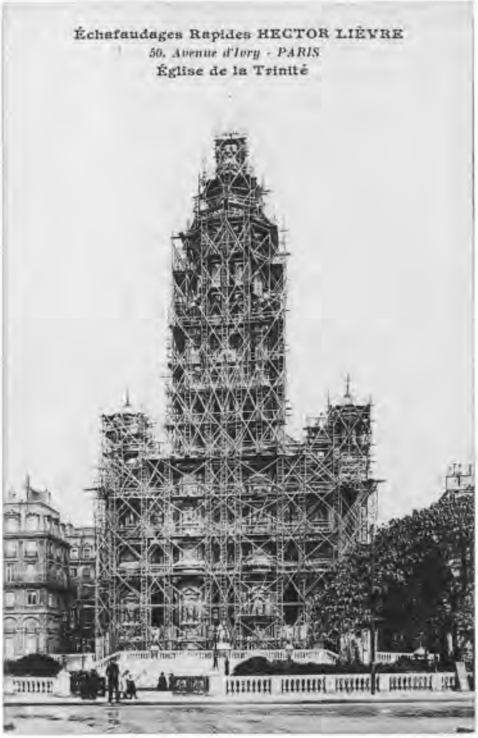

Figure 2. An advertising postcard published by Hector Lièvre with the Trinity church under scaffolding in 1921.

Although Hector Lièvre succeeded in suggesting that this ladder scaffolding system was entirely his invention, some pieces of evidence suggest that reality was probably more complex. In the text of his patents, Hector Lièvre referred in the following terms to an older patent: “Scaffolding known as Rapid Scaffolding formed by means of ladders, diagonals, connecting and fixing devices are already known (French patent of 13 December 1894, no. 243.614)”. It should be noted, however, that he was careful not to specify that he was neither the author nor the current owner of this first patent. This patent referred to by Hector Lièvre had been registered by an engineer called Funcke in 1894. It had then been licensed to a Mr Haupt in January 1904 and sold to Ms Haupt, his widow, in June of the same year.

3 LADDERS AND BRACKETS

The 1884 patent registered by Jules Funcke begins with the following assertion: “The purpose of this invention is to provide a scaffolding system for restoration and other similar work, which is safe, quick and economical to erect. It makes it possible to suppress the beams

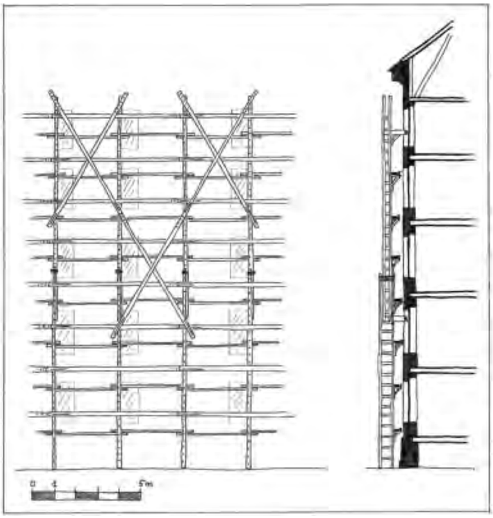

Figure 3. Jules Funcke’s patent. Elevation and section. Redrawn from the original patented drawings.

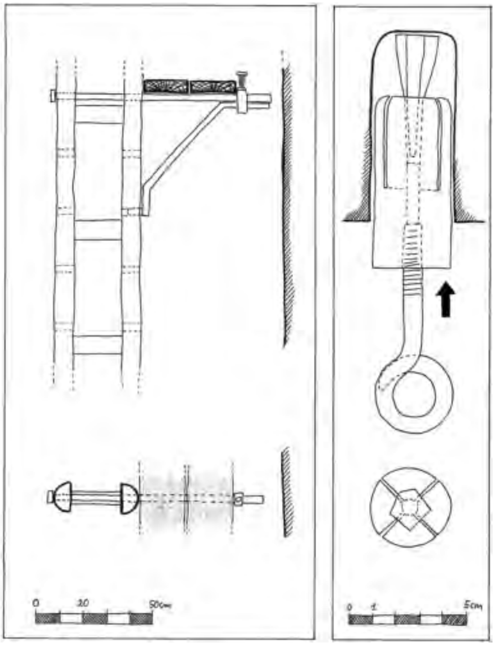

Figure 4. Jules Funcke’s patent. Set-up of brackets and timber floors (left). Wooden dowel (right). Redrawn from the original patented drawings.

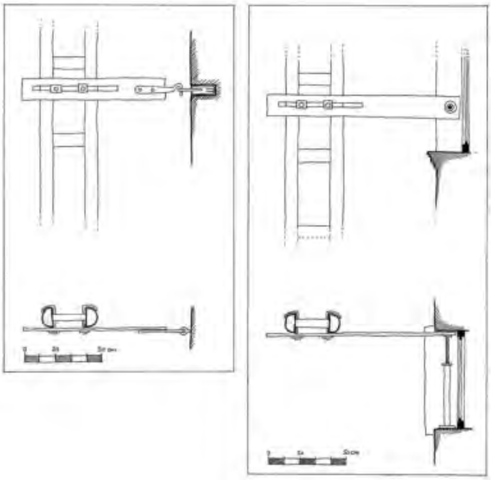

Figure 5. Jules Funcke’s patent. Two anchoring solutions. Hook and dowel (left). Braces between the boards of the building (right). Redrawn from the original patented drawings.

and ropes generally used to attach the scaffolding to the framework or any solid enough part of the building whose façade is to be renovated, repainted or cleaned. The panels of my scaffolding are held against the building by means of special devices that are very simple to use and do not require sealing or any other work that could damage the building”. This is followed by carefully detailed written explanations completed by several drawings. The original drawings have been redrawn in order to get a better comprehension of the general device (Figures 3, 4 & 5).

The general set up of the scaffold system shows that the ladders were set perpendicularly to the facade and that one ladder could cover between two and three floors (Figure 3). The elevation drawing also shows the St. Andrew’s crosses and the horizontal crossbeams securing the ladders together and also acting as railings. The timber floors were laid on removable iron brackets consisting of a straight bar and a triple bent brace, joined by a bolted sleeve tightened by means of a pressure screw (Figure 4, left). The patent suggests two possibilities to anchor the scaffolding to the facade. The first alternative is a horizontal strut jammed between the reveals of the bays in the building (Figure 5, right). This strut holds a plank with a slot holding a clamped hook which embraces the ladder. The other anchorage alternative is a hook and piston device fixed in the facade with a wooden dowel (Figure 5, left). The wooden dowel is affixed in a hole in the facade by a kind of expansion system pushed in by sledgehammer blows (Figure 4, right).

The patent ends with a propriety claim about four points:

1. The scaffolding system itself with ladders, connected by horizontal crosspieces of adjustable length and braced by St. Andrew’s crosses. The removable brackets supporting the scaffolding floors.
2. The construction of the brackets.
3. The fixing of the aforementioned scaffolding against the façade of a building, by means of braces jammed between the boards of the bays of the building.
4. The device for the solid fixing of pitons and screws in walls.

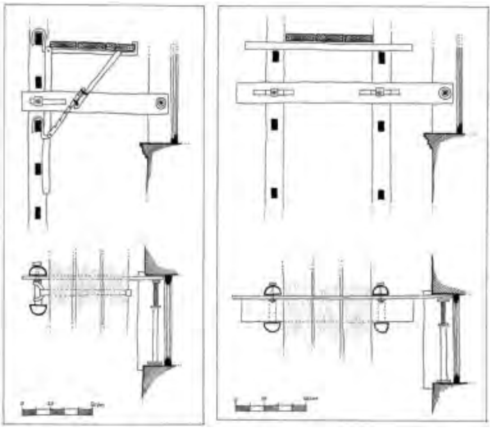

Figure 6. Extrapolations made from Jules Funcke's patent. The Boillot bracket (left). Hector Lièvre's ladders (right).

The postcards of several Parisian buildings wrapped with Hector Lièvre's scaffolding show a system similarly set up with vertical ladders (Figures 1, 2, 7). The ladders are parallel to the facade and they look like they were set up in pairs supporting a straight bar. This straight bar was carrying the timber beams where workers stood (Figure 6, right). In some pictures where the facade is narrow, there is only one line of ladders. In that case it seems that he did not use brackets but rather laid the beams directly across the ladders.

A 1930s catalogue from the Boillot company, which also dealt with *Échafaudages rapides* and various other construction components, details some components available to build ladder scaffolding with removable metallic brackets. This is illustrated with pictures very similar to Lièvre's postcards.

These descriptions can be completed by some additional documents from German-speaking areas in the form of several pictures or postcards. These pictures are too few to reach any conclusion. However, the fact that they show scaffolding with ladders set up perpendicularly to the facade like Jules Funcke's patent gives some food for thought all the same.

4 UNANSWERED ISSUES

4.1 *Direction of ladders*

The first issue is the positioning of the ladder. As explained above, Jules Funcke's patent used ladders perpendicularly to the facade whereas the Hector Lièvre pictures show ladders set up parallel to the facade. Besides, Jules Funcke used only one row of ladders whereas Hector Lièvre mostly used two rows. This means there was actually two different systems both using ladders. But, if that was the case, one might wonder why Hector Lièvre made a reference to Jules Funcke's patent as if he was just making an addition to an already existing system and why he did not register a patent of his own with his parallel ladders.

Besides, the pictures from Germany and Austria depict a system set up according to Jules Funcke's patent, which may have travelled there through the mysterious Mr and Ms Haupt who bought the patent in 1904. It is also possible that this idea appeared independently around the same time or that Jules Funcke used a German or Austrian patent as an inspiration for his own. As things stand, there is not enough information to draw any conclusions nor even venture a plausible hypothesis.

4.2 *Brackets or transom beams*

The second issue, directly related to the first, concerns the way the timber floors were set down on the ladders. One of the main claims of Funcke's patent rests on the metallic brackets supporting the timber beam floors and this is exactly the system pictured in the German and Austrian scaffolding of the 1970s. The Boillot catalogue also shows parallel ladders and adjustable metallic brackets—claimed as their specific product. Whereas, as far as we can see in the pictures of Hector Lièvre, the floors were laid on transom beams set between two ladders, a layout which meant a double row of ladders. Hector Lièvre sometimes used a single row of perpendicular ladders but in that case, the floors were set down directly across the ladders which leads to further questioning.

As the ladders drawn in Jules Funcke's patent are thirty centimetres wide, this means that either the Hector Lièvre scaffolding walkways were very narrow or his ladders were not the same width as Jules Funcke's. Furthermore, one might also wonder how it was possible to cross a ladder without walking over the void between the ladders and the building.

4.3 *Load capacity*

The third issue concerns the load supported by the floor. The scaffolding in front of the Trinity Church was erected in December 1904. While an invoice issued by Hector Lièvre's scaffolding company stated that 3,600 francs were paid for the assembly and rental of scaffolding over a three-month renovation period, it was not dismantled until December 1905, one year later. Newspaper articles published at the time commented abundantly on the fact that not only had scaffolding remained in front of the church for such a long time that passers-by had quite forgotten what their church looked like but also that no workers or any works were ever seen on it. A response to one of these critical articles questioning the architect and the scaffolding company was published on 6 September, 1905 by the company. The argument being that a company called Rapid Scaffolding should be able to move the works forward a little faster, it explained the aforesaid rapidity was only related to scaffolding assembly and dismantling and not to the actual works. The reason behind the lack of progress in the works was to be found in the lack of budget with the city council failing to provide the funding necessary.

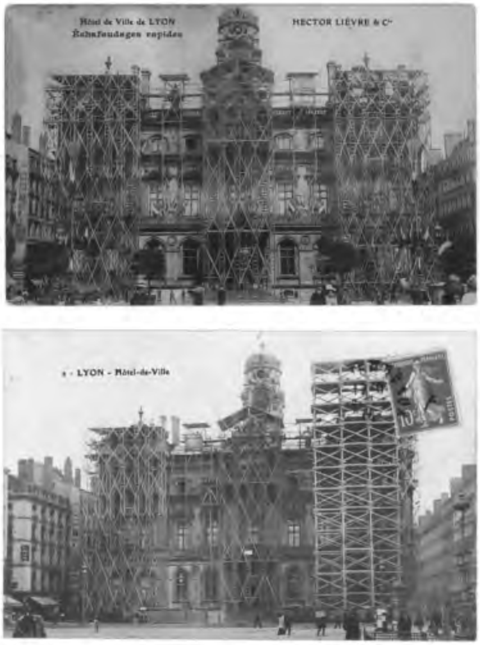

Figure 7. Postcards of the city hall in Lyon under scaffolding. Hector Lièvre's advertising version (above). The second scaffolding layer (below).

In May 1921, this scenario was repeated as new scaffolding, again provided by Hector Lièvre's company, was erected in front of the façade. It was not dismantled until November 1922, eighteen months later. As journalists resumed their more or less satirical articles on scaffolding where no worker was ever seen working, the explanation put forward was a little different this time. Having conducted interviews with the church priest and the municipal authorities, journalists provided the following explanation. Ladder scaffolding was light scaffolding only suitable for examination purposes. It only served to carry architects and experts in charge of analysing the building in order to decide what works ought to be done. Other, stronger scaffolding was to be built for the actual renovation works. One might be surprised by this statement, which contradicts the indication on the invoices that the scaffolding had to be able to support a weight of 1000 kilograms per linear meter. However, as soon as it was dismantled in November 1922, the ladder scaffolding was effectively replaced by more massive new scaffolding that stayed there until 1925. This seems to support the idea that it was not strong enough to carry out renovation works.

There are no mentions of this in the few known texts issued from Hector Lièvre's Company, nor in the patent registered by Jules Funcke. Nevertheless, further information is available in the pictures of two buildings under scaffolding: the Saint-Maurice cathedral in Angers in 1910 and the city hall in Lyon in 1911 (Figure 7). In both cases, a postcard shows ladder scaffolding in front of the facade with another layer of scaffolding partially covering the first. This second layer is not built with ladders and looks much sturdier. It may have been what is known in French as a *sapine*, a scaffolding external tower used only for access and the hoisting of materials. But the pictures do not show a square-planned tower but rather another layer of scaffolding along the facade. Besides, access ladders—different from structural ladders, can be seen in the first scaffolding layer. So, this may sustain the hypothesis that stronger scaffolding might have been needed to support greater loads of material. Still, if this external new scaffolding did provide means of working with heavier materials while keeping the original scaffolding, one might wonder why this solution was not used in Paris?

5 QUICKER, CHEAPER, HIGHER

5.1 *Guidelines*

The study of patents and pictures without more context is not enough to fuel a reflection on the question of innovation. This reflexion can be enriched by historiographical sources to help to find some guidelines. So far, scaffolding history has not given rise to a rich flow of research findings. As historians who have taken an interest in the subject have rightly pointed out this is mainly due to a lack of sources. Although scaffolding is often an indispensable element in the construction process, its temporary nature leaves few traces on the buildings—precisely the point. The available sources consist mainly of iconographic representations and texts. Rare through they may be, quite interesting research works have been carried out on the basis of these few iconographic and textual sources, relying also on the traces left on the buildings themselves.

Analysis of these research works brings to light five main issues:

- The anchoring, or lack of, on the building, a question linked to the issue of obstruction of the ground.
- Accidents and concerns for the safety of workers.
- The height scaffolding can reach and the different techniques best or least suitable to achieving this height.
- The loading charge of the floors and whether they have to carry only workers or also materials.
- The economy of construction, an issue which covers the quickness of assembly—including ligatures, the possible reuse of elements, their potential prefabrication and the material types.

As the above analysis of this ladder scaffolding system has shown, these five lines of thought each run through this enquiry. If we review them from the point of view of innovation, two may be ruled out, namely security and the load carried by the floors.

A brief mention is made about security in the patent with mention of "horizontal rails, made of planks, also serving as guardrails" for the workers. But this is not claimed as an innovation and indeed railings have been attested by iconographical studies of earlier periods. About the load the scaffolding can carry, there are no specific claims on this subject unless inventing a scaffolding system that may not be able to carry any great load is considered an innovation.

5.2 *Anchoring*

A point described both in the patent and in Hector Lièvre's discourse is the issue of anchoring. They both explicitly mention putlog scaffolding to explain their system proposes something entirely new in that respect. They will leave no more holes in the facade or any traces whatsoever. Only Jules Funcke expands any further with the description of a supposedly new anchoring system with "braces jammed between the boards of the bays of the building". It is quite difficult to ascertain the novelty of this proposition. As it claims to leave no traces on building, it is no wonder that there does not seem to be previous traces of such anchoring on buildings but it is also rather improbable that nobody before ever thought of anchoring something on a building with such a method.

The second interesting point about anchoring is the hook. Although Jules Funcke claimed no hook would be required, he then proceeds to describe another possible anchoring system with hooks screwed in wooden dowels inserted in holes drilled into the facade. So, it seems there may be traces on the building after all. This proposition claims novelty in the absence of plaster to fix the hook in the stone. However, the idea of fixing metallic hooks in a facade and leaving them in place for further uses has some precedents, in Rome at least (Holzer 2018). What may be new is the spited technique of wood dowels, which is an ameliorated version of the older wedge principle.

The question here also lies in the distinction between built-in scaffolding, a structure where the building is part of the scaffold's structure and self-standing scaffolding that may need to be anchored to the building for safety purposes in case of wind but which could theoretically be constructed on a standalone basis. This distinction has frequently been made in previous works (Albrecht 2018; Baud et al. 2002; Ensergueix-luthereau 1995; Fitchen 1989; Holzer 2013). Actually, Hector Lièvre's pictures and Jules Funcke's drawing shows that this particular device does not belong to any of these two categories. The structure is assembled independently from the building which does not have a structural role; in that respect, it could be classified as belonging to built-up scaffolding. But this is very different from any sturdy trestle and it is wildly improbable that such a high and narrow light structure could stand alone without being anchored to something right from the beginning of its erection. This is supported by Hector Lièvre's patented drawings. In these, the umbrella—namely an almost horizontal protection for workers and buildings under work is drawn with additional braces when covering an empty area. One of his postcards of the construction of a wine warehouse in the Bercy district in Paris depicts a big scaffolding structure covering the still empty would-be warehouse space with additional oblique braces.

5.3 *Economy*

The point most stressed both by Hector Lièvre and Jules Funcke is the economical aspect of the system. It is visible in the reiterated mention of a lower cost in Hector Lièvre's documents and in the semantic choice of *rapide* as a qualifying adjective in the name of his company. This economical aspect lies mainly in the proclaimed use of pre-existing ladders which reduce the assembly time of the structure as some part of it is already assembled. These ready-made ladders are supposed to ensure a quick assembly and a reducing of the cost.

The second economical aspect, at least in the Jules Funcke case, is the use of removable metallic brackets instead of crossbeams and ropes. Historiography has shown that scaffolding reuse was an already known practice. Putlog scaffolding, in particular, was devised for an easily dismantled reusable standard. This reuse could be to reassemble the same scaffolding sometimes in the same building as part of a maintenance plan (Holzer 2018). It could also be for completely new constructions.

Hence, the possible new feature may lie in the use of ladders. Although workers on ladders are pictured in previous iconographical sources, there does not seem to be traces of ladders used as scaffolding with the kind of set-up analysed here.

What is neither mentioned nor shown is the manoeuvrability of this ladders for they must indeed have been quite heavy and not so easy to manipulate. The ladders in Funcke's design are 9.5 meters long. So, the advantage of a kind of prefabrication must have been weighted against having something less easy to handle and less adaptable. A discussion which falls into the already-known argument between prefabrication and custom-built.

5.4 *Height*

The last point is the height reached by scaffolding. This point is not mentioned in any of the available texts. But the study of the thirty-one Lièvre Postcards brings to light how the main iconographical argument is that about height. These pictures all show scaffolding rising above the building as if to reach the sky. The necessity to reach really impressive heights with scaffolding is not a new one and the construction of many great European monuments triggered a lot of ingenious ideas in that regard throughout history with flying scaffold (Holzer 2018) or high-level hung scaffolding in gothic cathedrals (Fitchen 1961) for instance. Putlog scaffolding could also be used to that effect by being displaced and reassembled higher in conjunction with the wall it helped to erect (Baud et al. 2002; Viollet-le-Duc 1868). But the difference here lies in the linear vertical development from the ground to the sky. This seems to be the first-known instance of built-up scaffold reaching such heights—64 meters high for the Trinity Church and 78 meters high for the Saint-Maurice Cathedral in Angers.

Besides purely technical questions, this issue of the height reached by scaffolding should be read in the light of our imagination of a construction reaching for the sky. If this question is probably always at stake in scaffolding imagination, it takes a new meaning here with the use of ladders. As Christian Heck has shown in his work about the celestial ladder, ladders carry a powerful charge of signification as an agent creating a link between the earth and the sky. They act as a tool in a quest for heaven (Heck 1997).

6 CONCLUSION

This complicated story shows that evidence on the subject of innovation is very elusive. In this respect, patents are kind of misleading. They might give us the impression that someone really did invent something at a very precise moment because they register a name and a description thus setting themselves down on paper at a given time. And, of course, they sometimes really record a definitive innovation. However, the truth was most probably far more complicated.

This attempt to draw a kind of genealogical tree of this scaffolding has been made by crossing factual data with tales and imagination. It reports how registering a patent is one thing and using it is quite another and that ownership is not always acknowledged as it should be. It also conveys how good advertising capacities can have a very great, and not always truthful, influence on the attribution of an innovation's origins. It also shows patents tend to add on the same very precise point, blurring the line around what the innovation was and where it exactly came from. This may be because innovation comes more from a circulation of ideas at a given time than from a distinct moment. These ideas may have some intake from a definite original source but they are mainly used and reused while being ceaselessly modified by the blending in of small alterations (Jacomy 1990).

Ultimately, this polyphonic enquiry underlines the fact that technological innovation is a complex matter that cannot be considered in its own right. Circulations of ideas and processes, advertisement schemes and the collective imaginative undercurrent are woven together in interconnected layers (Colomina 1994).

The postcards come from a private collection.

Figures 3, 4 & 5 have been interpreted and redrawn by the author from Jules Funcke's original patented drawings.

Figure 6 is a personal proposition by the author based on Jules Funcke's drawings.

All translations from French by the author.

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History of Construction Cultures – Mascarenhas-Mateus & Paula Pires (eds)

The emergence of electric arc welding in the construction and reinforcement of railway bridges in France, 1930s–1940s

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ABSTRACT: Construction of electric arc welded railway bridges developed in France with the work of Chief Engineer Louis Eugène Cambournac (1886–1973) within the Compagnie des Chemins de fer du Nord from 1935 onwards, then within the SNCF (French Railways) from 1938. Under the impetus of this Chief Engineer, about ten railway bridges were built, including only one truss bridge, the Joncherolles Bridge, put into service on 15 May 1939. During this period, the electric arc welding process was used to reinforce riveted bridges not strong enough to support the increase in loads and frequency of railway traffic. It was also used for repairing corroded riveted railway bridges, and occasionally following destructions that occurred during the Second World War. This study shows, in this transition period, how the electric arc welding process quickly – but quite lately – became established for the construction of French railway bridges, replacing the hot riveting process.

1 RAILWAY BRIDGE CONSTRUCTION BEFORE 1934

Since the First World War and in parallel with oxy-acetylene welding, electric arc welding underwent a considerable development, fully justified by the results that can be applied to a very large number of applications (Granjon & Salelles 1939). But the application of welding in bridge construction was rather modest before 1930, and this has several causes, like the uncertainty about the adequate behaviour of welded joints and the difficulties in designing shapes well adapted to welding because of the practices imposed by riveting (Goelzer 1947). Gradually, the difficulties were reduced: on the one hand, the welding technique was considerably improved and on the other, the design teams became familiar with new shapes that led to the design of welded assemblies.

Thus, the first two welded railway bridges in the world were built in the United States of America: in 1927 at Turtle Creek in the state of Pennsylvania and in 1928 at Chicopee Falls in the state of Massachusetts (OTUA 1936); this bridge had a span of 41 m and weighed 80 metric tons (Goelzer 1947). OTUA also reports that four railway bridges were built in 1929, including two in Melbourne, Australia (35 and 41 metre spans), one in Weiz, Austria, and one in Biel, Switzerland.

From 1930 onwards, the number of welded bridges gradually increased worldwide, with more than 50 welded Vierendeel-type road bridges in Belgium (Espion 2012). Likewise, for railway bridges, when nine rail bridges were built in the world between 1930 and 1934 (Sire & Ragueneau 2019a). Despite that in France, the first welded structure had been erected in 1928 (D'Angio 1995) and many tests had shown the possible replacement of riveted joints by welded assemblies, the first circular on steel structures with welded connexions was only issued in 1934 (Ministère des Travaux Publics 1934).

2 WELDING WORKS AT THE COMPAGNIE DES CHEMINS DE FER DU NORD

2.1 *Chief Engineer Louis Eugène Cambournac (1886–1973)*

Louis Eugène Cambournac was born in Paris X in 1886 and died in 1973 in Nice, France. He entered the École Polytechnique in 1905 and was admitted to the École des Ponts et Chaussées in 1907. Chief Engineer of Works and Surveillance at the Compagnie des Chemins de fer du Nord, he became Director of Operations for the SNCF's northern network in 1938. Following the decree of August 1937, The Société

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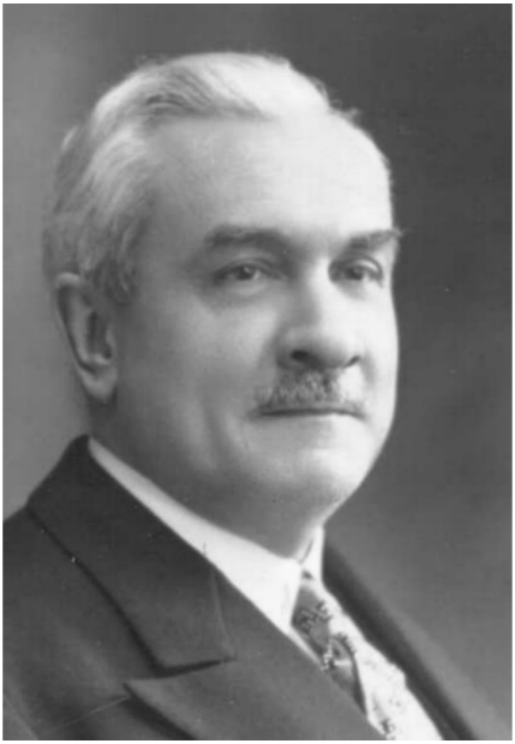

Figure 1. Louis Eugène Cambournac, Private collection Colonel (H) Arnaud Cambournac.

Nationale des Chemins de fer Français was created on 1 January 1938. It included the five major railway companies of the country: the Compagnie des chemins de fer du Nord, the Compagnie des chemins de fer de l'Est, the Compagnie des chemins de fer de Paris à Orléans, the Compagnie des chemins de fer de Paris à Lyon et à la Méditerranée and the Compagnie des chemins de fer du Midi. In 1944, he became director of the Personnel Department of the SNCF; see Figure 1 for a portrait from that time. He was awarded the Legion of Honor.

As early as 1934, Mr Louis Eugène Cambournac, Chief Engineer of the Compagnie du Chemin de fer du Nord, considered the construction of a welded railway bridge to give French construction the opportunity to follow a direction already used by industry in other countries. Thus, he stressed that the provisional circular of 1934 (modified 1935) came nearly four years after the first welded railway bridge built in Germany (Cambournac 1937a). He was encouraged not only by this general reason, but also by the great confidence he had acquired in electric welding, which he had recommended as early as 1926 for use in the construction of railway crossings and switches (Widman 1950).

For instance, with the intention of avoiding any subsequent intervention by maintenance teams, Cambournac built a welded switch; 1700 switches of this type were in service in 1937. From its numerous tests, first with the cooperation of the Soudure Autogène Française (choice of electrodes, technique of welding execution, training and control of the welders), Cambournac concluded the following general rules: welded assemblies can support high and repeated stresses, welded assemblies can resist repeated shocks, the risk of quenching can be considerably reduced and internal stresses due to welding can be important and the welding procedure is therefore crucial. These principles convinced him of the relevance of the application of electric arc welding for the construction of railway bridges.

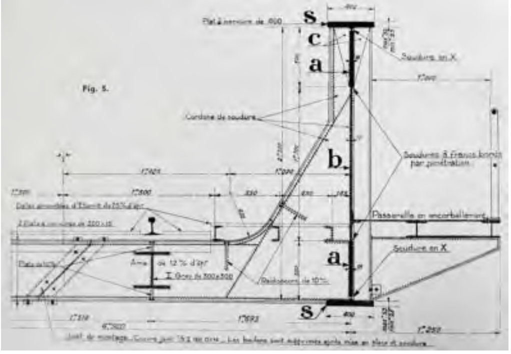

Figure 2. Bridge at La Plaine Saint-Denis, transverse half-section of a welded spacer.

2.2 *Welded railway bridges from 1935 to 1939*

Granjon & Salles (1939) stated that electric arc welding could not replace riveting where the construction methods had demonstrated technical or economic advantages. However, the German Engineer Schaper (1936) noted that welded constructions were generally cheaper than riveted constructions. Long after the construction of the first German welded railway bridge in 1930, this technology was used for the construction of six welded bridges between 1935 and 1939 on the French railway lines. The northern network was equipped with four more welded bridges between 1945 and 1949 (Widman 1950).

Prior to these constructions, the very first of them was a small 24-metre-long swing bridge for 225 metric ton locomotives. It was built by the Maison Paindavoine from Lille and opened in 1935 at the Joncherolles depot on the edge of Saint-Denis, seven kilometres from the Paris-Nord train station (Cambournac 1937a).

2.2.1 *Bridge at La Plaine Saint-Denis*

In service on 11 May 1936, this bridge is inclined at 11°. It has two high lateral girders with full plated web, constant height, one-lane spacers and stringers, see Figure 2 (Paindavoine 1937). Its weight is about 164.5 tons. Made of Ac 54 Thomas steel, it is fully welded. The Maison Paindavoine from Lille used "Safer spécial L 40" type electrodes from the Soudure Autogène Française (Cambournac 1936, 1937b; Paindavoine 1937).

Figure 3. View of the bridge over the Boulevard Ney, photo taken by S. Sire, August 2020.

2.2.2 *Bridge over the Boulevard Ney at the Porte de la Chapelle in Paris*

This bridge has been in service since 10 August 1936 for the left lane and since 14 October 1936 for the right lane. Although this bridge is welded, it has the particularity of having the webs consisting of IPN 450 stringers riveted to the spacers. For the calculation of this bridge, the axle weights of the standard train of the 10 May 1927 regulation were increased by 10%. In addition, the circular of 25 July 1935 on welded assemblies imposes, on the one hand, for butt welds at ends carried out on site, a tensile stress equal to 75% of the stress in the base metal, and, on the other hand, a 50% increase in the effects due to rolling overloads (Gauthier 1937). The Ateliers de construction Schwartz Hautmont used a mild steel type Ac 42. The triangular characteristic legs of this bridge consist of a 20 mm web with a 400×50 plate welded to the upper section and 400×52 plates welded to the rest of the perimeter, Figure 3. The total weight of the structure is 470 metric tons and the Arcos-Stabilend electrodes were supplied by La Soudure Electrique Industrielle in Paris (Bureau d’études de l’Arcoservice 1937a; Widman & Mucherie 1937).

2.2.3 *Le Bourget bridge*

Le Bourget bridge was in service on 14 April 1937, it weighs about 74.5 tons (Widman 1950). The Maison Baudet, Donon et Roussel built this structure in Ac 54 Thomas steel and carried out numerous tests to verify that the base metal and the electrodes were compatible. They thus chose electrodes of the Arcos-Superend brand (Baudet 1937; Bureau d’études de l’Arcoservice 1937b).

The main girders have parabolic shape, with a full web and are 3.05 metres high in the middle and 2.1 metres high at the ends. Their flanges are 32 mm thick and 350 mm wide. The deck was first assembled in the workshop using angle irons provisionally welded by a flange to the elements, to be assembled and bolted together by their free flanges before being disassembled and then welded on site, see Figure 4 (Baudet 1937). The angles were then removed during the welding of the structure.

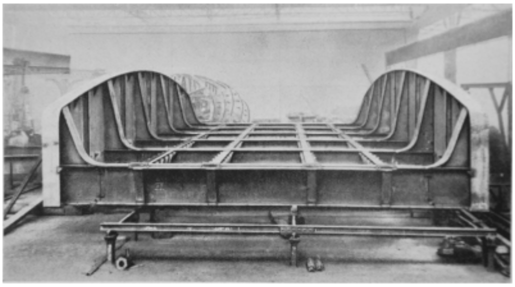

Figure 4. Le Bourget bridge, assembled in the workshop.

2.2.4 *The Landy bridge*

In service on 10 April 1938, the Landy bridge is a two-lane ballasted bridge with three solid web girders with parabolic top chords and spacers embedded in a reinforced concrete slab for tracks without stringers. The structural elements are mainly made of Thomas Ac 54 steel. The Etablissements Schmid, Bruneton and Morin used “Citogène” brand electrodes (Schmid 1937).

To reduce deformation due to weld shrinkage, the following principles were applied:

- Simultaneous and symmetrical execution with regard to the median plane of the parts.
- Use of the back step welding technique starting from the middle of the welds.
- Flat execution of all welds.

Transported fully welded to the construction site, the beams were installed using a 32 metric ton SNCF crane, stabilized by temporary bracing, then fitted with their spacers and reinforced concrete slab.

2.2.5 *The Landy Street bridge*

In service on 4 February 1939, it belongs to the twin-beam type joined by spacers on which the track rests through stringers. Its weight is 24.5 metric tons. Built in Ac 42 steel by Etablissements Schmid, Bruneton and Morin from Paris, it has no special characteristics (Widman 1950).

2.3 *The Joncherolles bridge, a first of its kind*

These first welded French railway bridges were built five years after the German rail bridges. At the Berlin IABSE Congress, Schaper (1936) stated that Germany had already made great progress in the field of railway bridge welding. Until then, only full plated web rail bridges had been welded. In France, the SNCF northern network undertook the construction of a welded Warren truss bridge to provide access to the Joncherolles locomotive depot.

The access being in a curve with small radius (300 metres) imposing a reduced speed of 60 km/h, Cambournac proposed to experiment a welded truss structure (Cambournac 1939). In service on 15 May 1939, it supports a 300-metre curved track, see Figure 5 (Roser 1939). Made of special steel Ac 54 and

Figure 5. The Joncherolles bridge.

Figure 6. Load test on the truss of the Joncherolles bridge.

fully arc welded, it had been studied and built by the Etablissements Schmid, Bruneton and Morin, under the direction and in constant contact with Mr Cambournac, and with the Specialized Services of the Northern Region of the SNCF.

Since the distribution of stresses at the nodes of a truss is not well known, studies have been conducted to reduce secondary stresses due to the stiffness of the truss connections and to avoid the cumulation of welds at the nodes. In addition, the engineers focused on reducing the thickness of the sections to be welded, keeping the welds accessible and minimizing welds on site.

The construction of the Joncherolles bridge is well documented and illustrated (Roset 1939; Schmid 1939a & 1939b; Widman 1950). Figure 6 shows in particular a workshop load test on the truss with a Manet-Rabut device in the foreground and, between the diagonals, an Huggenberger strain measurement device (Schmid 1939b). These devices provided information on the strain state, making it possible to compare the corresponding stress in the parts with the results of the calculations.

Due to the application of welding to a trussed structure, the Joncherolles bridge has often stirred apprehension abroad. After its opening, it was subjected to new fleximetric, tensimetric and radiographic tests (Widman 1950). Conducted in January and July 1948 and combined with radiographs taken in August of the same year, these tests gave complete satisfaction (Widman & Schmid 1948).

According to Cambournac (1939), it was a first step towards the original shapes made possible by welding and which would lead if confirmed, to the abandonment of thick cross sections.

2.4 *Post-World War Two constructions*

Following these constructions, and after the Second World War during which bridge repairs were undertaken (see next section), the SNCF northern network built four other fully welded metal bridges between 1945 and 1949 (Widman 1950). These bridges are all made of Ac 42 steel:

- Stors bridge on the Ermont to Valmondois line, in service on 20 November 1945, built by the Etablissements Schmid, Bruneton and Morin.
- Compiègne bridge on the line from Compiègne to Silly-la-Poterie, in service, for both tracks, since 12 October 1946, built by the Etablissements Schmid, Bruneton et Morin.
- Abbeville bridge on the line from Amiens to Boulogne, in service on 25 October 1946, built by the Etablissements Schmid, Bruneton and Morin.
- Bridge of the Porte de Douai in Lille on the line from Lille to Béthune, in service on 31 August 1949, built by the Paindavoine Company.

3 ARC WELDING REINFORCEMENT AND REPAIRS

At the same time as these new constructions, the French Railways also introduced welding works on riveted bridges, mainly made of wrought iron. Two kinds of welding works were considered for existing riveted bridges: reinforcement and repairing. Reinforcement works are done by using arc-welding to add new sections to existing parts of the bridge. Repairing works consist in replacing damaged parts by new ones welded in order to build up again full sections.

SNCF acquired a large experience in the reinforcement of wrought iron riveted bridges since the 30s: mechanical tests were systematically done on welds carried out on wrought iron decks in 1933 (Vallette & Goelzer 1948). Amongst all French reinforced wrought iron bridges, one of the most important was the national swing bridge over the Penfeld river at Brest which supported an increase in traffic and the passage of the tramway from 1898 (Lecomte 1938; Sire & Ragueneau 2019a). Another example of a wrought iron bridge reinforced by welding was the bridge over the Ill River near Strasbourg (Lang 1936) strengthened with Martin steel elements according to a design by A. Goelzer. The stresses calculated in the iron elements greatly exceeded the allowable limits (11 kg per mm^2).

Other bridges, such as the Jean-François Lépine bridge, underwent repair and reinforcement works, particularly because of corrosion issues that weakened sections of structural elements (Goelzer 1936a). Thus, stringers, floor beams and main girders were repaired and reinforced to comply with the regulations, see Figure 7 (Martinet et al. 1936). Moreover, it was

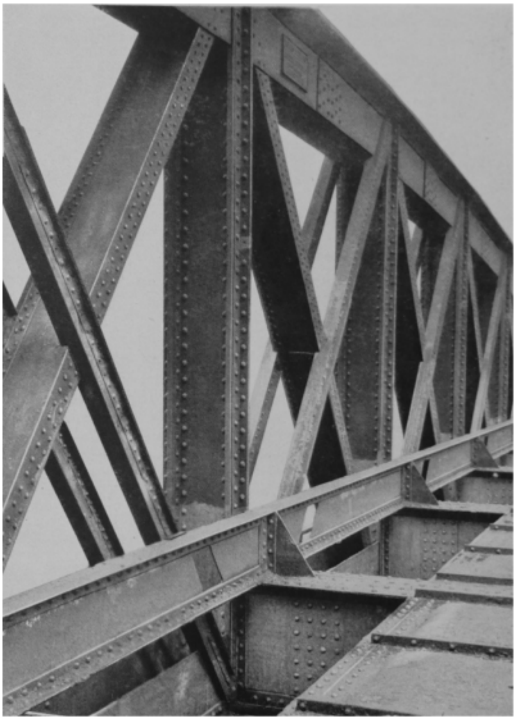

Figure 7. Repaired beam of the J-F Lépine bridge.

the expertise gained by the Eastern Railway Company during earlier works on the reinforcement of corroded elements and riveted elements with ovalized holes that led to the decision that the large 75 m long railroad signal support of the new Reims station should be entirely built using electric arc welding (Ridet 1936).

Furthermore, the choice of the strengthening steel was also studied. Therefore, the ductility properties of the strengthening steel are considered more relevant than its strength properties (Fauconnier 1939). Thus, a mild steel type A37 was preferred to a high strength steel type A52 in the reinforcement of the Austerlitz viaduct over the River Seine (Fauconnier 1936; Sire & Douroux 2015).

Many railway bridges were also particularly damaged during the Second World War. Although the SNCF tried to replace steel decks with SNCF standard structures made of steel-concrete composite slabs with or without ballast, or even reinforced concrete (Cayla 1942), some steel bridges were repaired by electric arc welding (SNCF 1942); the Oissel bridge is one example (Vallette & Goelzer 1948). According to these authors, it is thanks to the experience acquired by SCNF services in the reinforcement of structures by welding that allowed the reconstruction of the Oissel bridge:

- The application of welds on 25 small decks of the Chartres to Bordeaux line.
- The reinforcement by SNCF of iron bridges (the Authion bridge, the Bezons bridge and the bridge over the Ill River in Strasbourg) by adding welded steel elements.
- The strengthening of the Brest swing bridge by the Ponts et Chaussées department.

4 DESIGN AND CONTROL

As described in the previous section with the presentation of some diverse welded bridges, several aspects have been particularly studied, namely the welding technique, the weldability of the materials and the calculation of the assemblies according to the regulations of the time. For this purpose, the static and cyclic loading characteristics of the different materials (base metal and electrode metal) and connections had to be determined.

4.1 *Materials assessment*

The allowable stresses in parts of railway bridges depending on the material used are well documented, see for instance Sire & Ragueneau (2019b). However, the use of welding interferes with the characterization because it is strongly dependent on the chemical composition of the metal. Baudet (1937) notes that steel companies were free to obtain steels with the characteristics required by the regulations. Thus, each steel producer had its own composition and this diversity in composition shows the care that the manufacturer took in welding such a poorly defined material. The difficulty was further increased by the number of electrode brands. Lévi (1939) even adds that within the same bar, specimens could give different results underlining the heterogeneity of some metals.

To overcome this difficulty, engineers carried out numerous characterization tests on riveted specimens combining the base metal of the structural elements and the metal of the electrodes, as described above.

But from the behaviour of the calibrated laboratory specimen to the behaviour of a complex welded assembly, the engineers also tested mock-ups to validate the good mechanical resistance of the assembly. Thus, for the reinforcement of the Austerlitz viaduct, different models (scale 1:1 and 1:2) were made to validate the constructive arrangement of the hinges (Sire & Douroux 2015). Similarly, during the construction of the Pont du Landy, a mock-up representing a stringer to floor beam connection was tested (Schmid 1937).

4.2 *Consideration of fatigue*

At the Berlin IABSE congress, the German engineer Shaper (1936) declared that welded beams have better resistance than riveted beams. However, the shape defects of the weld cords raised the question of the behaviour of welded connections under cyclic loads (Gerbeaux 1939). Goodman's diagrams show the results obtained for different stress regimes (Goodman 1930). Figure 8 shows a fatigue strength diagram of welded mild steel connections (Gerbeaux 1939).

Numerous tables from tests carried out worldwide present the allowable stresses for welded joints

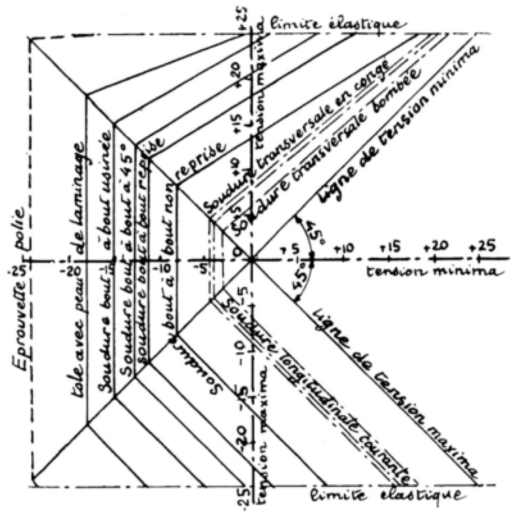

Figure 8. Fatigue strength diagram on mild steel assemblies, in French.

subjected to cyclic loads or fatigue test results (Dutilleul 1936). Among these, we can cite for instance Goelzer (1937) and Martinet et al. (1936).

4.3 *Defects and control of welds*

Leroy (1939) presents a classification of the different defects observed in weld beads. He insisted on the metallurgical heterogeneity as well as on the presence of non-metallic impurities. He determined the causes of these defects: the incorrect choice of the filler metal, the conditions of execution, the shape and arrangement of the assemblies, the weldability of the base metal.

Inspection of the weld aspect was therefore necessary; micro and macrographic analyses also allowed the identification of defects such as porosities or inclusions. As magnetic inspection was not yet sufficiently efficient, radiographic X-ray inspection was recommended. Thus, the bridge at la Plaine St-Denis was inspected radiographically before and after the prescribed tests; this inspection would allow periodic checking of the service behaviour of the welds by taking new pictures (Widman 1950; Widman & Schmidt 1937).

Semi-destructive testing using a Schmückler milling machine could also be conducted to reveal imperfections within the welded joint. This tool was for instance used during the inspection of the reinforcement welds of the Austerlitz viaduct: every visible defective weld was indeed tested with the Schmückler milling device as well as all other welds every six metres (Sire & Douroux 2015).

At the Berlin congress, Schaechterle pointed out that welding stresses can become so high that they can cause cracks when steels are poorly chosen. Thus, internal stresses endanger constructions when welding initiates cracks (Schaechterle 1936). In particular, he mentioned high carbon and silicon content welds with rolling errors. Moreover, Goelzer pointed out that according to Dutilleul, porosities are responsible for the low fatigue strength of some tested welded assemblies (Goelzer 1936b).

In the issue of *Le Génie Civil* of 11 June 1938, which appeared shortly after the Hasselt bridge in Belgium (Espion 2012) H. Gerbeaux, head of studies for welded constructions at the Institut de Soudure Autogène, stated that no welded bridge had collapsed in France. He attributed the failure of the Hasselt bridge, a Vierendeel-type, to incorrectly executed welds. It also indicated pre-existing cracks and the poor quality of the Thomas steel used. Metallurgical considerations were apparently little developed to explain welded assembly failures. Thus the issue of considering the ductile-fragile transition temperature and the brittle fracture of steels in the construction of French welded railway bridges has not been identified in this study.

5 CONCLUSIONS

After experimenting with electric arc welding on small bridges, in the repair of corroded or damaged structural elements, in the strengthening of riveted wrought iron bridges so that they could support the increase of traffic, the French Railways built several fully welded bridges from 1935 onwards. Louis Eugène Cambournac, Chief Engineer at the Compagnie des chemins de fer du Nord, was a pioneer in this venture which was shared and discussed a lot, as the publications of the time show.

Among the six welded bridges he built on the railway lines of the northern network, one of them, the Joncherolles bridge, was a truss bridge, the first of its kind. The determination of the deformations due to the thermal cycles induced by welding being particularly delicate, the construction of a welded truss railway bridge is a remarkable achievement.

Also used in strengthening and repairing existing riveted bridges, the riveting was gradually replaced by electric arc welding for the construction of French railway bridges.

This study needs to be extended to understand how the notion of brittle fracture has been taken into account in welded railway bridge construction.

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History of Construction Cultures – Mascarenhas-Mateus & Paula Pires (eds)

Development and rationalization of formwork for curved concrete shells in the Japanese construction industry in the 1950s

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ABSTRACT: The popularity of shell structures in post-World War II Japan led to the construction of many reinforced concrete spatial structures. Against a backdrop of Japan's sophisticated traditional wooden construction techniques, many of these novel shell-structure formworks were also made of wood. This paper explores the development of the general formwork method in the postwar period and its relationship to the impact of US military-related construction projects and the industrialization of the construction formwork method. Case studies of shell-structured roof formwork and shoring from the 1950s are presented and discussed, and the methods of their construction are analyzed. During the early days of formwork, curved structures were fabricated using log-framed shoring and wooden panels. However, over time, steel reusable falseworks (pipe supports and turnbuckles) came into use. The development and industrialization of the construction method are analyzed through the evolution of the method of formwork construction.

1 INTRODUCTION

1.1 *Background*

The reinforced concrete (RC) membrane theory of shell-structure and construction was introduced into Japan during the 1920s (Uemura et al. 2019). As an example, in volume 32 of the magazine *Kenchikusekai*, published in 1938, the Jena Planetarium, constructed as a spherical shell, created by Carl Zeiss & Dyckerhoff and Widdman was introduced, along with German long-span buildings in general, using photographs and quotes from European architectural magazines (*Kenchikusekai* editors 1938). Several dome-shaped concrete structures, including the Kasuisai Gokoku Pagoda (1911) and the Meiji Memorial Picture Gallery (1926), had been constructed (Kawaguchi et al. 2019), but no details are known of the construction of these curved surfaces.

Although attempts were made at the research level, such as the airplane hangar shell-structure study carried out by the Yoshikatsu Tsuboi Laboratory during World War II (WWII) (Tsuboi 1953a), no long-span RC shell structures had been built in Japan by the end of the war.

Japanese industry suffered toward the end of the war and stagnated due to its repercussions and the payment of war reparations. Around 1950, industrial revival and development began to take place against the backdrop of demand triggered by the Korean War. New experiments in architecture began to appear, and large-span structures, such as warehouses and theaters, were built. In the years following the war, RC thin shell structures were often used for large-span structures because steel materials were expensive and because they offered resistance to fire and a high degree of design freedom (Kato 1953).

Due to the sophisticated woodworking skills of Japanese carpenters and the low cost of their labor, wooden formwork accounted for a large proportion of formwork for in-situ concrete. This continues to be so up to the present day, and these skills and methods are also widely used for shell-structure formwork. In the immediate postwar period, curved-surface formwork was constructed using log supports and wooden stripes or panelized boards. Later, after the introduction of US-style construction methods, the formwork gradually became industrialized. However, despite its evolution and thanks to sophisticated wooden technology and the availability of cheap labor, there has been no study of the development of curved-surface formwork or the changes in construction methods and industrial structures over time. In effect, the details of the development remain unknown.

1.2 *Purpose and structure of this paper*

In study, the modernization of formwork construction in 1950s Japan and its industrialization are analyzed through case studies of curved-surface formwork construction methods. These methods used traditional techniques of wood carpentry in the formwork construction of large structures.

Section 2 describes the gradual modernization of Japanese formwork construction, triggered by orders for US military-related projects.

Section 3 presents an analysis of case studies of the curved-shell formwork constructed in the 1950s. These case studies are based on reports published in issues of the magazines *Shinkenchiku*, *Kenchikuzasshi*

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and *Kenchikugijyutu*, all of which were published during that era.

Section 4 gives a summary of the development of curved-surface formwork in the 1950s and changes in construction methods in accordance with the changes that took place in industry organizational structure. This section also suggests avenues for future research.

2 INDUSTRIALIZATION OF THE CONSTRUCTION OF FORMWORK AND SUPPORT IN POSTWAR JAPAN

2.1 *Formwork construction in the pre-war era*

Concrete buildings only began to be erected in Japan in the 20th century, and wooden formwork was used from the beginning of this process. Robust sheathing plates, used in constructions from around 1910, were made of planks over 5 cm thick. A handbook for work in concrete produced around 1920 describes a formwork assembled onsite by nailing 26 mm hick stripes to a 10 × 10 cm balk base (Yoshida 1921).

In 1917, Yasaku Kojima from Shimizugumi (which would later become the Shimizu Corporation, one of the five largest general contractor companies in Japan), developed a wooden unit panel with 21 mm thick stripes framed with 72 × 36 mm balk. This unit panel became widely used across Japan. The standard size for these fixed-measure panels was 6 × 2 *shaku* (a *shaku* is a traditional Japanese unit of measure equaling 303 mm; thus, the panel unit was approximately 1818 × 606 mm). This remains the standard panel size in wooden formwork today. Nails were used to secure the panels to the formwork, and the formworks were tightened onto clamps and other hardware with whips (Uchida Award Committee 1990).

Formwork construction is now established as a professional field, but in its early days, carpenters worked on both formwork and wooden structures.

2.2 *Acceptance of US-style concrete work methods and modernization of construction methods*

The modernization of Japanese formwork construction was prompted by the construction practices of the US occupation. In the construction project of the Atomic Bomb Casualty Commission, the Hijiyama Research Institute in Hiroshima (1950), under the guidance of US architects and using US materials, it was required that construction work be carried out to US standards to an accuracy of 2 mm or less (Hino 1950).

The use of whips was not permitted, so a type of hardware called a bolt was developed to tie and hold the forms. For the sheathing, 18 mm thick boards with tongue-and-groove joints were adopted for a permanent form finish, and veneers were used for fair-faced concrete.

Under the occupation, US military construction projects began in Okinawa in 1948. First, US contractors were commissioned to construct military base facilities, but after April 1951, the commissions for these constructions were put out to international tender, and Japanese contractors participated in bidding and construction.

From this point on, Japanese construction materials began to be used, but US form-ties were supplied and brought back to the mainland to be made into prototypes by Japanese engineers who were employed by hardware manufacturers, creating an early example of domestic form-ties. At this time, formwork hardware and construction methods were developed by hardware manufacturers, following on the ideas of construction engineers who had had experience with US methods (Uchida Award Committee 1990).

2.3 *Promotion of steel supports*

The need for reusable, high-precision steel supports had been recognized since the 1950s. This was due to lumber shortages caused by the construction rush triggered by the high economic growth and the popularity of fair-faced concrete finishes during the middle of the decade (Ouchi 1954).

Scaffolding experiments conducted for long-span structure construction were carried out by major construction companies (Figure 1). A support system of this type that was suitable for Japanese construction methods was developed by the Shimizu Corporation Research Department, and it began to be used around 1952 (Kurachi 1953). Steel supports were also introduced around 1954 by the Taisei Corporation, one of the five largest construction companies in the country

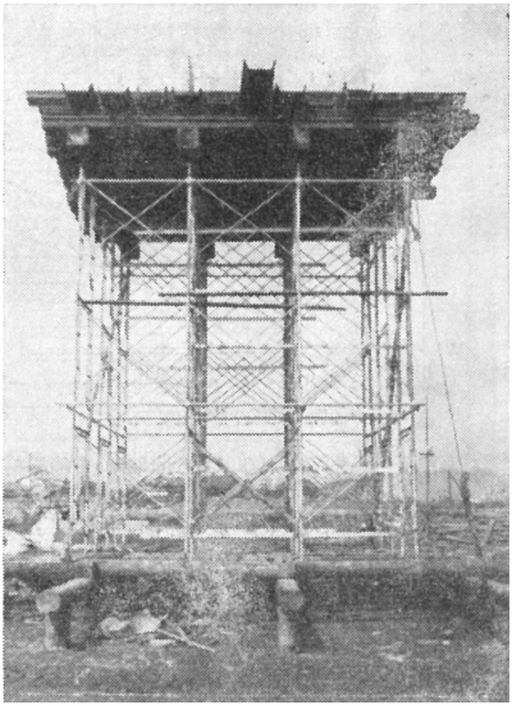

Figure 1. Load test for a pipe scaffolding structure (Muto 1961).

(Taisei Corporation 1969). By 1955, most temporary works in urban areas had been replaced by steel supports (Nagai 1955). Beams were also increasingly made of steel and, from 1955 onwards, they were piped. The telescopic beam system appeared around 1960.

In 1959, steel supports were standardized in the Japanese Industrial Standards by the Japanese Government.

2.4 *Advent of plywood sheathing panels*

Plywood sheathing panels appeared in 1952, and stripes and wooden unit panels were already in widespread use. Plywood was still not commonly used in sheathing due to the problem of mortar separation. However, after a study by Yasuhiro Kameda (from the Building Research Institute of Japan) et al., plywood sheathing panel came into wide use around 1969 (Architectural Institute of Japan 2001).

This sheathing formed the basis for the modern Japanese method of formwork construction, which is still in common use today.

3 ANALYSIS OF CURVED FORMWORK IN THE 1950

3.1 *Subjects of analysis*

This section analyzes examples of curved-shell formwork constructed in the 1950s. In the early 1950s, most shell structures were spherical and cylindrical, but gradually, larger and more complex shell structures were developed. Meanwhile, formwork structures were initially constructed using the conventional method, which consisted of setting logs and wooden sheathing plates using whips. Gradually, steel supports were introduced into certain parts of the construction, and the construction method was devised. This section analyzes two spherical shells, four cylindrical shells, one saw-tooth shell, and a swept-surface shell.

3.2 *Construction of shell structures with log frame formwork using conventional methods*

At the introduction of shell structures in Japan, during the first half of the 1950s, formwork was constructed using conventional log methods, and sheathing was made of either 1800 × 600 mm panels, the standard size, or stripes. There were no official guidelines for formwork construction at the time, and quite a few accidents occurred due to the use of the method of shoring without structural calculations and the construction of supports on unstable ground.

(1) Tsurumi Warehouse (1951)

One of the earliest shell-structured roofs completed in Japan was the Tsurumi Warehouse (1951) in Kawasaki (Kato 1951). This building was originally built to protect gasoline tanks from aerial bombardment during WWII, and it was converted into Japan's first long-span shell warehouse by placing a spherical shell-structure roof, with a diameter of 40 m, over a cylindrical concrete wall (Kato 1953). The 7 m high roof consisted of a 100 mm thick slab at the top, which gradually increased in thickness to 45 cm at the edge. The roof had a 1.2 m diameter exhaust at the top and 100 glass blocks embedded in the shell to allow in light. The design was created by Nihon University's Kaoru Ono Laboratory, which was responsible for the design of many early shell structures. The construction was carried out by the Taisei Corporation (Figure 2).

The shell formwork was built using the conventional Japanese wooden method. Because the columns were constructed to support a 9 m high stage, they were built by connecting two logs using a socket joint. Horizontal timber columns were placed at 1.2 × 1.2 m, and log braces were placed at every other row. The beams and joists, which consisted of logs passed over the column, and 1.8 × 0.6 m panels, the standard sheathing panel size in Japan, were laid orthogonally on top. Where there were surpluses in the spherical plane, wooden stripes were fastened to the joists onsite. The strips were stabilized in two places in the center and in four places along the perimeter by pulling from below with whips.

(2) Sangenjaya Central Theater (1952)

The Sangenjaya Central Theater in Tokyo was a cylindrical shell structure (Figure 3). Like the Tsurumi project, log-framed supports were used. Roof truss

Figure 2. Tsurumi Warehouse (Kato 1951).

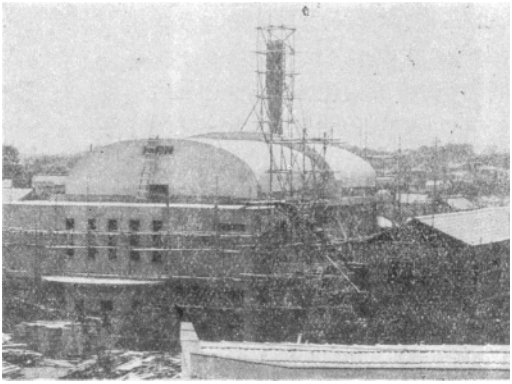

Figure 3. Sangenjaya Central Theater (Ono & Kato 1952).

frames were built onto the stage onsite, with joists added (Ono & Kato 1952).

The roof consisted of two shells, one of 11.4 × 10.2 m and the other of 11.4 × 9.7 m, connected in a row. Each shell had a 2.5 m rise and a slab thickness of 9 cm at the top, with a 13 cm thickness at either end. In cross-section, the shells were not perfectly circular but close to elliptical in shape, with their curvature gradually increasing as it approached the edge. The structure was designed by Toyo Kensetsu, and the structural design was also carried out by Nihon University's Kaoru Ono Laboratory.

For the supports, logs were placed upright on a 1.5 m grid, horizontal connecting logs were laid out at a 1.4 m pitch, and an 8 m high work stage was set up on the logs.

Roof truss frames were assembled on the stage using 10 cm square timber at a 1.5 m pitch, and 10 cm square timber was crossed over as joists at a 60 cm pitch. As with the Tsurumi Warehouse, 1800 × 600 mm sheathing panels were used. However, because the curvature was increased at the edges, 24 mm thick curved ribs were built, and 15 mm stripe boards were laid on to follow the larger curvature. The top cover was also made of stripes to prevent the concrete from flowing out during casting.

(3) Ehime Prefectural Citizens' Hall (1954)

Ehime Prefectural Hall is a masterpiece of early concrete shell work, which combined the architectural skill of Kenzo Tange and the structural engineering of Yoshikatsu Tsuboi. The spherical shell, 50 m in diameter and with 133 circle top lights of 60 cm in diameter, had a rise of 6.5 m and a thickness of 12 cm (Domyo 1954). Due to the limited number of RC projects at the time, few designers and builders had experience in the construction of shell projects. Eiji Domyo, a former colleague of Tange at Maekawa Associates, was asked to supervise the construction (he had earlier managed the construction of Kagawa Prefectural Government Office and the Hiroshima Peace Center).

For the falsework, columns with two socket-jointed logs were set in a radial pattern from the center, at a pitch of 1.8 m. These were joined horizontally, vertically, and diagonally with braced logs. Two level stages were built, at 6.1 m and 9.7 m, depending on the height of the ceiling. The columns of the upper structure were erected on the stage just above the lower column, with the use of turnbuckle-wire fastening to prevent vertic al and horizontal bracing and lifting.

The log girders were laid out in a radial pattern directly above the support column, and perpendicular to these girders, log beams were laid at a 0.9 m pitch with 45 cm pitch joists in a radial pattern on the beams. On top of these, a sheathing of 18 mm thick pine stripes with half lap joints were laid between the parallel boards (Figure 4).

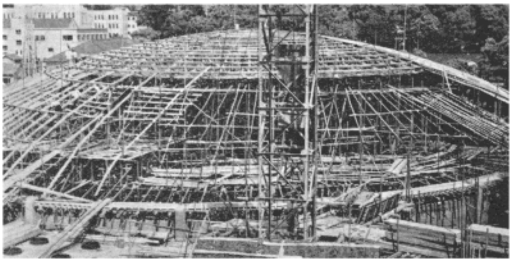

Figure 4. Formwork installation of Ehime Prefectural Citizens' Hall (Tsuboi 1953b).

(4) A film studio in the suburbs of Tokyo (1954)

In the 1950s, formwork and temporary scaffolding had not yet been standardized, and constructions that used them often collapsed during construction. On 4 January 1954 three workers were killed in a concrete pour during the construction of a film studio with a 33.3 m span cylinder roof in a suburban area of Tokyo. (Figure 5). An accident investigation was conducted by the National Institute of Industrial Safety, Japan. A detailed verification of the accident was reported in *Kenchikugijyutsu* (Saito 1954). This report included a detailed description of the structure of the formwork and its support from before its collapse. A 9 m log, 15 cm in diameter at the base and 6 cm in diameter at the tip, was erected on a 2.25 × 2.25 m grid with a working stage built on top. The upper structure of the stage supporting the formwork was also made of logs, with a pitch of approximately 1.00 × 2.25 m, and the connecting material and the pillars were joined with whips.

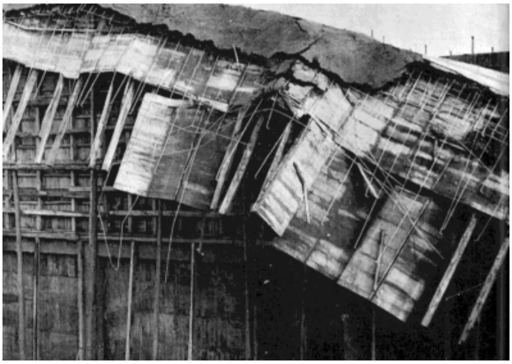

Figure 5. Collapse of a formwork structure during its construction (Saito 1954).

The footings of the upper structure columns were not fixed and were only occupied by wedges, and a site inspection observed traces of floating during the casting process. In addition, the footings were not vertical and would have been prone to buckling. The cause of the collapse was considered to have been the lifting of the foot of the upper structure or the buckling of the upper structure during the pouring of the concrete.

3.3 *Introduction of steel support*

Around 1954, the construction method of steel supports began to be used by major general contractors and in the construction of temporary structures.

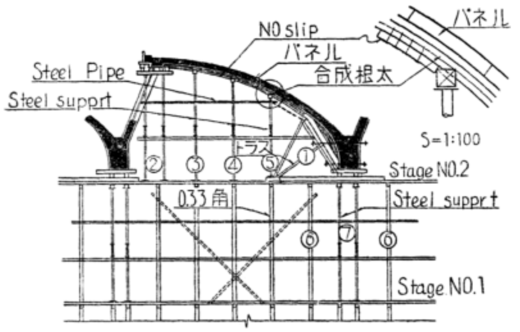

Figure 6. Section of formwork of tooth shell roof (Tsuboi et al. 1954).

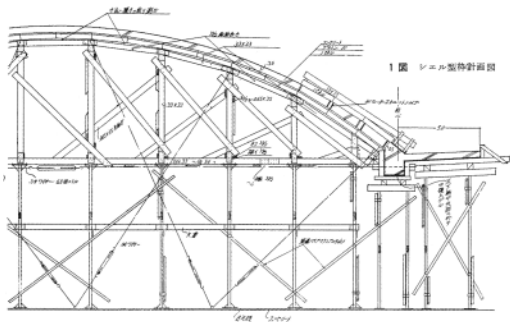

Figure 7. Section of formwork of the lecture hall of the International House of Japan (Iguchi & Hoshino 1955).

This was at first only seen in urban areas, but it gradually spread throughout Japan.

(5) Dainippon Printing Ink Manufacturing Tokyo Plant (1954)

In the mid-1950s, Ichiro Ebihara and the Yoshikatsu Tsuboi Laboratory designed a number of shell structures for the Dainippon printing plant. *Kenchikuzasshi* reported the details of the saw-tooth shell roof formwork used in these multiple shell construction cases in its edition No. 817 (Tsuboi et al. 1954). This was the first reported shell construction using steel supports in the surveyed cases. The roof consisted of seven cylindrical shells that were 20.7 m in length and 7.2 m wide. Each cylindrical shell had an 8.5 m radius, was 1 cm thick, and had a tilt angle of 23˚ to create an opening for a high sidelight. Unlike the four previous cases of log support, this support structure was made of 10 × 10 cm square timber and steel pipes. The steel pipe supports were only used in the main beams and for the roof supports of the upper structure on the stage. To ensure that the timber would be reused as much as possible, planks were avoided, being replaced with a combination of panels of various sizes, which could be reused for other formwork projects. Composite joists were used to create and sustain the curved surface. These were made first by stacking thin stripes and bending them onsite to fit the shape of the curved surface and then stacking and fixing them with screws to develop joists of a sufficient cross-sectional size. These composite joists could also be dismantled and reused as stripes elsewhere (Figure 6). This method was developed by the Tsuboi Laboratory after testing for adhesive strength, and it continues to be used in Japan today in the onsite assembly of curved-surface formwork (Ito 2018, Hayashi et al. 2019)

(6) Lecture hall in the International House of Japan (1955)

The International House of Japan, built with donations from the Rockefeller Foundation and others, was designed by three of Le Corbusier's Japanese disciples – Kunio Maekawa, Junzo Sakakura and Junzo Yoshimura – with additional structural design by the Tsuboi Yoshikatsu Laboratory and construction by the Takenaka Corporation. The lecture hall was built with a cylindrical shell of 18 × 11.4 m rising to a 7.5 m roof (Iguchi et al. 1955). Pipe supports were used for the stage supports during the construction work.

The girders and brace of the support structure on the working stage were constructed of 100 mm square timber.

The sheathing was panelized, and the height of the surface was measured and adjusted onsite. Wooden and steel columns were mixed together for the eaves, and the stress on the posts during demolding was measured to be nearly the same when the wooden column was removed, indicating that the wooden posts took little of the stress (Figure 7).

3.4 *Advent of large unit formwork*

During the early days of formwork for shell structures, the supports were erected first, followed by the beams, joists, and sheathing panels, which were assembled onsite. However, a new method of construction emerged, in which the trusses were pre-assembled in the groundwork and then lifted and installed during the onsite stages. This truss structure grew even further with the appearance of large-scale, transformed formworks designed for moving and lifting.

(7) Osaka Castle Shooting Range (1954)

The Osaka Castle Shooting Range was designed by the Osaka Construction Department of the Japan Self-Defense Force, and it was built on the grounds of Osaka Castle. It consisted of a row of triple, simple, swept-surface shells (Figure 8). Each shell was 14 × 10 m (Osaka Construction Department of the Japan Self-Defense Force 1956).

Two methods to produce the formwork structure were considered. The first was to assemble columns and beams on the working stage onsite, and the second was to assemble the truss structures on the ground and set them onto the stage. The truss method was chosen for the simplicity of its assembly and disassembly and for the workability of the operations under the structures.

The trusses were 13 m wide and 2.5 m high, with cedar chords of 9 × 3 cm and cedar webs of 1.5 ×

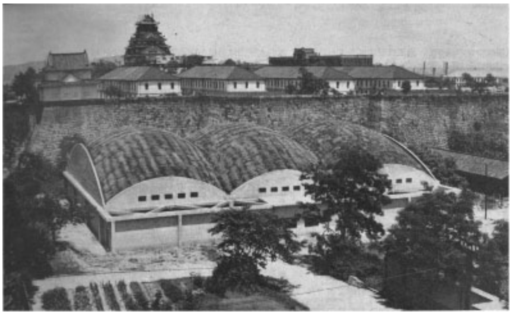

Figure 8. Three shells of the Osaka Castle Shooting Range (Osaka Construction Department of the Japan Self-Defense Force 1956).

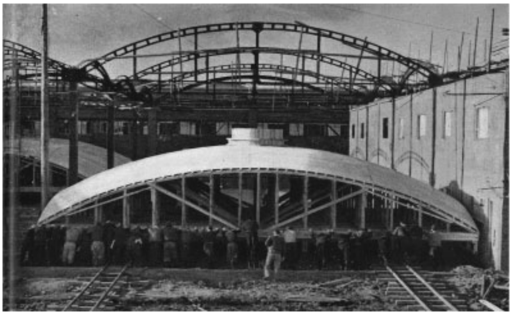

Figure 9. Formwork unit for shell roof moved by manpower (Sumiya 1956).

7.5 cm, fastened by nails. The trusses are hung on the stage and set at 60 cm intervals. The overall height was adjusted using wedges, and a 12 mm thick board was placed on the trusses to create a sheathing that remained in place after demolding and was used as base material for the ceiling finish.

(8) Okayama Plant of Kurashiki Rayon (1956)

For the construction of the Okayama Plant of Kurashiki Rayon, a traveling form was adopted to divert the formwork itself by moving it. A huge structure of integrated wooden trusses was created for the construction of the cylinder shell. Several examples of this had been built internationally, including at US military warehouses and the Building Research Institute of the Ministry of Construction of Japan, but this was the first large-scale project of this type in Japan (Sumiya & Kitamura 1956). Shintaro Urabe, who later became an independent architect and contributed to the development of the city of Kurashiki, worked at Kurashiki Rayon, managing the building and repairs section and supervising construction.

The factory building was constructed on a 54 × 54 m plan and was made up of six rows of cylindrical shells. Each shell was divided into three equal parts in the direction of the ridge, and the formwork was diverted and concreted into three parts. The formwork was one-third the length of one cylinder, and each individual unit was 160 m^2. The formwork was made of a wooden truss structure, supported by steel pipes, and it was assembled in such a way that only the posts under the rim beam could be dismantled. The steel pipe supports under the rim girders were equipped with rollers that slid in the direction of the ridge. The sheathing was made of 6 mm thick plywood, and the stripping agent to demold the plywood was carefully selected.

A large number of man-hours was required to move one unit (9 × 18 m) up and down. Ten scaffold builders were needed, along with and one *kagurazan*, a traditional heavy lifting and transporting machine used in Japan that is moved by people through pushing and turning a wheel. Each movement of the formwork unit to the next casting area took 40 minutes and required 0.1 people per square meter. It took an entire day to lift one formwork unit up or down.

In the following year, Kurashiki Rayon built an additional 30,000 m^2 of shell-structured roofs using the traveling form method (Sumiya 1956; Figure 9).

For these projects, using a power winch and four laborers, it took 15 minutes to move a 42 × 42 m formwork a distance of 42 m. New lifting jack equipment was developed to reduce the required labor to move the formwork units, cutting the man-hours by at least half and reducing the lifting time to three hours.

4 CONCLUSION AND FUTURE STUDY

This study focused on the development of curved-surface formwork in Japan in the 1950s and analyzed the development of construction methods through changes in industrial structure and the industrialization of construction methods.

Immediately after WWII, formwork construction was modernized due to the industrial influence of US-style construction work, with general contractors carrying out full-scale experiments and developing methods under the supervision of university research institutes and structural engineers.

In the mid-1950s, steel support scaffolding was partly used as a shoring method, but when shells were introduced, log frames were used for the first time, and a combination of steel scaffolding and wooden sheathing or superstructure became common.

Two methods for making curved surfaces and support structures onsite were the most common. The first required the most assembly onsite, with the supports erected first, followed by assembly of the beams, joists, and sheathing plates. The second method used pre-assembled trusses that were lifted and installed onsite.

During the 1960s, the construction boom that sparked by the work for the 1964 Tokyo Olympics and the resulting mass migration of workers to Tokyo led to an emergence of specialist formwork contractors, and a split emerged between normal wooden frame carpentry and specialist formwork carpentry. Beginning in the mid-1960s, thin plywood became more commonly used for sheathing plates. It was also during this period that curved-surface manufacture was increasingly outsourced, and companies that specialized in curved formwork began to emerge.

In future research, we intend to further investigate these important changes in industrial structures and the evolution of the methods of curved-surface formwork construction in the 1960s.

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Danish spheres and Australian falsework: Casting the Sydney Opera House

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ABSTRACT: By shedding light on the contribution of local ingenuity and craftsmanship in the making of one of the most celebrated buildings in the world, this paper reveals the largely unacknowledged, detailed complexity behind the fabrication of the iconic roof of the Sydney Opera House.

1 INTRODUCTION

> "So far as I can see, it would not be easy to calculate and detail your plans so as to give justice to your ideas with full clarity and still make them economically possible. Nor do I believe you can count on Australian workmen and Australian technical resources being on the same level as the Danish".
>
> (Ove Arup to Jørn Utzon) (Murray 2004: 12)

Although Jörn Utzon and Ove Arup candidly expressed their reservations on Australian know-how, Australian workers and technical resources were crucial for the construction of the Sydney Opera House (SOH) in the 1960s. Indeed, while it might not have been so evident in the eyes of the two Danes in 1957, Australia possessed a long and solid tradition in concrete, the main material employed in the production of the shells considered the most striking feature of Jörn Utzon's winning design.

By shedding light on the contribution of local ingenuity and craftsmanship in the making of one of the most celebrated buildings in the world, this paper takes Arup's words to task, in the process revealing the largely unacknowledged, detailed complexity behind the fabrication of the iconic roof of the SOH.

The first attempts to build with concrete in Australia date from the late 1800s and, by the early 1900s, had also come to concern the erection of important nation-building infrastructures such as the Melbourne Public Library (1906), with its 35 m-diameter octagon surrounded by stacked-book annular and surmounted by what was then the largest reinforced concrete dome in the world (Saunders 1959), or institutional complexes like the Newman College at the University of Melbourne (1917) featuring a rotunda dome built in reinforced concrete with crisscrossing cuspid-like ribs forming structural arches (Turnbull 2004). However, in spite of the formal potential expressed by these structures, reinforced concrete was mainly used as a structural medium and rarely exhibited in building exteriors. Indeed, while concrete was well represented in the Australian construction industry, by the time of the SOH competition it was still often hidden behind brick, stone or terracotta cladding. All-reinforced concrete building was by-and-large limited to civil engineering structures (such as silos, bridges and tanks), and mostly as an in-situ material. In Sydney, concrete was used extensively for maritime works aiming to tame the coastline of the famous city's harbour, for which precast techniques were also pioneered – the lighthouse at Bradleys Head, Sydney (1904) being one of the most notable and first examples of exposed precast concrete.

With few exceptions – for example, the Knitlock system (Watson 1998) for houses developed by Walter Burley Griffin and David Charles Jenkins in 1917 – it was only after World War II that, with brick and structural steel in short supply, concrete and precast concrete started to be used more widely and exhibited. This was the case of the "Concrete House Project" promoted by the Housing Commission in Victoria, which boosted the development and production of precast elements, culminating in the construction of 30-storey blocks considered to be amongst the most sophisticated precast concrete structures in the world for the time. By the mid-1950s, there were over a dozen concrete manufacturers operating in Australia, as well as many engineers who were beginning to learn the calculation methods required for precast concrete (*Concrete in Australia* 1977). Alongside its

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development, which increased the speed of construction and enabled the reduction of on-site labour, the construction industry looked with great interest at pre-stressing techniques fit to exploit the potential offered by precast modular construction while stabilizing it through post-tensioned high-tensile steel wires.

Post-tensioning made its first appearance in 1953, in the construction of a segmental single-span bridge (21.2 m) at Island Bend, New South Wales. The bridge preceded the renowned Gladesville Bridge over the Parramatta River, completed in 1963, which was laterally pre-stressed with longitudinal post-tensioning, and was showcased as the longest single-span, concrete bridge in the world at the time (O'Connor 1988). With necessities and economic reasons driving the development of a solid knowledge of concrete, the material started to be used in a variety of ways, capable of fulfilling designers' aspirations and interests. As a result, from the 1950s, Australia witnessed not only a large use of concrete in architecture but also a variegated application of the same: thin concrete shells, off-form concrete structures, and precast panels with local exposed aggregates gained more and more space in the country's architectural landscape. Among the many buildings, the shell for the Shine Dome, Canberra (1954), the precast hyperbolic paraboloid for the roof of the St Kevin's Church, Dee Why (1961); the IBM House, Sydney (1964); and Australia Square (1967), the second tallest skyscraper in the world at the time, portray a general idea of the creative use of reinforced concrete in Australian architecture and its construction industry (Stracchi 2019). In New South Wales, the industry-leading builder was Civil & Civic (eventually acquired by Lendlease), a company with a sound know-how of concrete construction (Steward & Taylor 2001). Civil & Civic was in fact behind the design and construction of the Unilever House, the Caltex House and the ICI building, Australia's first examples of International Style multi-storey buildings, which employed innovative concrete structures and techniques (*Concrete in Australia* 1977). In 1959, Civil & Civic was appointed as main contractor for the construction of stage I of the SOH – foundations and podium – which included the implementation of the intricate exposed concrete soffit for the entrance concourse.

It was within such an energetic concrete construction culture that Utzon and Arup built their SOH – indeed, a collective enterprise that benefitted not only from the creativity of the two Danish masters but also from the craft of the many Australian concreters and concrete specialists trained on the grounds of the local industry.

Among the extensive body of references and publications about the construction of the SOH, there are comprehensive technical appraisals. One is the report written by Arup Engineers' central figures Sir Ove Arup and the project lead Sir Jack Zunz, and published in the Arup Journal in October 1973 (Arup & Zunz 1973). The report chronicles the unfolding of different aspects of building the SOH, such as the development of the podium-beams, the evolution of the shells' geometry to accomplish structural stability and building repetition (the legendary spherical solution), the structural analysis of the roof, and the engineering of the glass walls.

Other studies that examine architecturally significant items include a monograph by the Hornibrook Group, the general contractor of stage II and III (Hornibrook Group 1973), an explanatory account of pictures from the building site (Pomeroy 1984), a "biography" of the spherical solution (Mikami 2001), and a scholarly analysis of the interiors' development, which focuses on the role played by architect Peter Hall in the completion of the building after Utzon's resignation (Watson 2017). Indeed, with the exception of an earlier publication by Anne Watson, from 2006 (Watson 2006), no published studies deal with the workers. The story detailed in the literature is mostly hagiographic of the project as a whole – a grand technical synoptic narrative that brings everything together whilst overlooking the micro-details of the trades involved, with their everyday challenges. This is the reason why, notwithstanding the wealth of references about the building, its physical history remains disjointed and anecdotal; by-and-large, the processes involved in its materialization over a period of approximately 15 years have yet to be detailed and organized. This is not a menial task. After all, throughout that time, at least 230 companies were contracted for construction-related services, tens of thousands of people passed through its site gates, union movements grew, and new applications of materials were discovered (Tombesi 2005, 2006; Tombesi et al. 2010; Watson 2006).

This paper is the first outcome of a research project started in 2019 with the aim of contributing to filling this gap. It analyses the contribution of the Australian construction company in charge of stage II to the production of the formworks and the concrete components that are the backbones of the sails of the SOH and considers its working relationship with the engineers from Arup.

2 METHODOLOGY

As suggested, the intellectual contribution of the general contractor in the making of the Sydney Opera House is largely unexplored. This may be partly due to logistical difficulties in locating the material necessary to analyse such contribution, as documents, technical drawings and construction pictures are kept in different locations in the state of New South Wales, Australia: the New South Wales (NSW) State Archives and Records in Kingswood; the Powerhouse Museum, in Ultimo; and the Mitchell Library, a department of the NSW State Library, in central Sydney. While relying on archival investigations for its relevant sources and documents, the research team had to go through a mapping process to locate essential items. Particularly, the emphasis was placed on identifying drawings and reports helpful to clarify how the contractor delivered, on-site, the information contained in the structural project. The authors took eight months to analyse and subsequently select these resources.

The archival investigation found materials never accessed thus far. In particular: a) a set of 85 drawings issued by the general contractor to build the concrete formwork for the iconic shells; b) 20 close-up pictures from the building site showing the process and the procedural challenges in casting the concrete; c) minutes from site inspections emphasising the problems occurring onsite day by day from 1964 to 1966; d) construction reports written to inform the Department of Public Works of New South Wales on the progress and tasks happening on-site; and e) the contract for the construction of the concrete sails.

3 THE GENERAL CONTRACTOR AND THE ENGINEERS

As widely known, the construction of the SOH was organized into three stages, in turn reflected in three different contracts: stage I for the construction of the podium; stage II for the construction of the concrete sails; and stage III for the remaining work necessary to turn the building into a functional art centre (Murray 2004). This essay focuses on the years between the date when the stage II contract was signed (18th of October 1962), and 1967, when stage II work was completed. The construction company responsible for the second and third stages was M R Hornibrook Pty Ltd, founded by the Australia-born Sir Manuel Richard Hornibrook (1893–1970) OBE, who was both a contractor and a civil engineer. The stage II contract covered the structural and civil engineering work involved in erecting the roof structure. The work was administered and managed by Arup as project manager.

The fruitful nature of the collaboration between Hornibrook as contractor and Arup as structural engineer can be seen in several documents. In some on-site tour notes (SANSW: NRS 18/1566.2), the principal structural designer of the SOH, Jack Zunz, wrote:

> "I'd like to say something about the Hornibrook. It is an all Australian firm. Sir Manuel Hornibrook, the founder, started as an artisan and is reputed to have socked his foreman on the jaw, packed his tools and the[n] started the organisation which is now one of the leading civil engineering contracting companies in Australia. MacDonald, Wagner and Priddle, our associated consulting engineers in Sydney, recommended them to us. We in turn recommended that the NSW Government, enter a cost-plus fixed-fee contract with them for the superstructure. For a variety of reasons we didn't think that it was feasible to follow conventional contractual procedure – chiefly because the method of building would have substantial repercussions on the design and also because vital decisions on design could be taken only when the method of constructing the roof had been agreed upon".

Zunz continues:

> "Much lip-service is paid to the designer–contractor relationship. In Hornibrook we have found a firm of contractors who are competent, well organised and experienced – and basically good imaginative engineers. We may well ask why we have so rarely worked so closely and harmoniously with a contractor on any other job, anywhere else. For many contractors are competent, well organised – and some are even good imaginative engineers. The answer lies in something that is beyond mere skill and technical competence. It lies in their attitude – which consists of a completely open and unprejudiced assessment of all new problems as they present themselves. And I can testify that in this respect they have been tried and not found wanting".

The key figure for Hornibrook was Corbet Gore, director of the company's NSW subsidiary, and project manager for the construction of stage II.

The fruitful and integrated collaboration between Arup and Hornibrook is clear by analysing the drawings for the structural projects issued by Arup. Before the involvement of Hornibrook, in 1961, the engineers had considered several possible methods of building the roof, ranging from a fully scaffolded scheme to a fully free spanning one. However, after signing the contract (SANSW: NRS 12686-2-(10/38191)), Hornibrook clearly contributed to many aspects of the very process. Further, a letter, dated 5 April 1962 and included in the contract for stage II, reveals that Corbet Gore and Rob Kynaston (also of Hornibrook) could spend some time in London at Arup to complete the construction scheme. This level of collaboration is also demonstrated in some structural components of the sails. These components are described in drawings issued by Arup but labelled "by Hornibrook". For instance, the spigots protruding from each rib block of the sails, developed to ease the assembly of the roof, were invented by the general contractor. Moreover, the extensive body of over 2000 drawings issued by Arup for stage II, was not the only way the information was delivered onsite. The authors also found over 300 drawings issued directly by Hornibrook. These drawings focus mainly on the intricate scaffolding systems, the steel arch used to erect the roof and, of course, the formwork systems. These panels, drawn with pencil on tracing paper, define even more precisely the inventive and intellectual role of the general contractor.

4 THE CASTING YARD

To investigate the array of concrete blocks delivered by the casting yard of the SOH and the inherent complexity of such endeavour, it is important to read and analyse the construction scope of the sails, i.e. the architectural element generating the need for it.

To this end, one must distinguish between its structural elements. The roofs of the Major and the Minor

Hall of the opera house each consist of three distinctive and structurally independent parts. Each part is formed by three different sets of shells jointed up by segmental arches. For each of these sets, one can identify a shell pointing to the harbour, another shell pointing to the city, and an arched structure connecting the two. The official documents named these parts as follows: the bigger shells are called "main", the smaller ones are called "louver"; the connecting structure is made of "side shells". They are in fact held by, or spring from, a tripod-like structure appearing on the outer surface like a fan, and made by arches named "octopus" that represent one of the most irregular parts of the whole roof in terms of geometry.

The shape of the main and louver shells is based on a sphere with a radius of 74.98 m (246 ft) to the outer surface of the structure. Each main shell and louver are part of this sphere, with its foot point at a pole of the sphere, so that each rib is geometrically described by a series of identical great circles. All the main and louver shells consist of several ribs with the exact same curvature but with different lengths. This allows a degree of repetition and segmentation of similar ribs into same components. The cross-section of each rib varies to increase its depth and width from the bottom to the top of the roof. A close "T" shape-like cross-section widens from the base to an open "Y" shape-like at the ridge.

The ribs could in fact be divided into segments. The longest rib is made of 14 components while the shortest one is made of two. Regardless of the rib being analysed, each component located at the same distance from the pole has the same cross-section. This allowed the generation of all the ribs components from the same formwork system containing all the segments in their natural sequence. At the top, each main shell joins a round-arched ridge beam also formed by a series of precast standardizable segments that maintain the same section throughout.

By comparison, the side shells require more parts and a completely different system of formwork than the ridge beam arch. Externally, the octopus arches are recognizable from a warped surface, which provides the visual and physical continuity between the main shells (or the louvers) and the side ones. Therefore, the cross-section of these arches is continuously varying, requiring a different set of formworks for their construction. As with the ribs, the octopus arches were discretized in and assembled with precast segments. These components are assembled by sitting on a first section in concrete cast-in-situ.

Consequently, aside from the pedestals of the main shells and the lower part of the octopus arches, the roof of the SOH is essentially made by precast parts. Specifically, the casting yard produced the following:

- the main shells and louvers shells' rib components, the crown pieces where the ridges of two shells meet
- the ridge beams' components
- the octopus arches' components
- the side shell beams.

Figure 1. The casting yard from the roof of Unilever House. NSW Archives and Records NRS:4_7927 (photographer unknown).

To address the fabrication of such a diverse range of components, the casting yard was divided into two main sections occupying the whole area of Bennelong Point towards the city (Figure 1). The western portion (nearest the wharf) was dedicated to precasting the warped segments of the octopus arches. The eastern portion was for the precasting of standard segments for the main ribs (Figure 2).

5 AUSTRALIAN FORMWORKS

The casting yard layout shows that these two areas were divided by rails used for the operation of two Whirley cranes employed to lift the segments from the formwork. Between the two main areas of the casting yard there was a third area used to cast the sub-components for the blocks supporting the standard ribs. These sub-components were necessary because each standard rib block was cast in several stages to ensure geometric accuracy on-site, and millimetric precision for the contact faces of different components upon their connection.

By analysing the contract for stage II, we understand that the formwork system was entirely engineered and fabricated by the contractor Hornibrook. The contract states:

> "It was agreed that formwork for the segments, octopus ribs, panels and other components, because of the complicated nature of the work and the impossibility of obtaining full drawings and specifications to enable tenders to be

Figure 2. The rib formwork system located on the eastern side of the casting yard. Photographer: Max Dupain and Associates. Records and negative archive: un-commissioned Sydney Opera House construction photographs, 1965–1972. Courtesy: NSW State Library.

> called, would be fabricated at M. R. Hornibrook (NSW) Pty. Ltd. Works at Enfield under the conditions laid down in Appendix 3 of the Conditions of Contract".

To assemble the whole formwork system on-site, Hornibrook produced at least 78 panels drawn in pencil on tracing paper (currently kept at the NSW Archive and Records). The formwork system was designed to allow maximum reuse. In the minutes of the meeting that occurred on-site on 12 November 1962, it is recorded that Gore reported that, on 20 November, they were expecting to run trials for the casting of some concrete ribs. During that time, the formwork was constructed at the contractor's headquarters in Enfield.

As indicated, each segment was engineered to be cast in small sub-components first. These sub-components were cast in reusable steel moulds, which can be seen in the pictures of the casting yard.

Subsequently, the sub-components were inserted into the main formwork system to be jointed together through the final casting phase, producing the block.

Sub-components differed in shape and role. The first type was the bulkhead diaphragms designed to be the separation between each rib block.

As it was reported, each rib widens from the base, with the cross-section of each component increasing in depth and width from a solid "T" to an open "Y". Therefore, several different diaphragms were necessary. As each rib-segment is composed of one bulkhead, and the number of blocks for each rib varies from 3 to 13, there were 13 different types of bulkhead constructed using the same number of steel moulds. The top chord of each rib varies as well. This variation occurs not only according to the height of the component but also according to its position on the shell surface. The majority of the top-chord lids are cross-bracing elements. When lateral stiffening between ribs is necessary, the block is cast with a different top chord, which is recognizable by rectangular pockets oriented like the steel bars. These pockets allowed the lateral bars to be screwed to the concrete blocks. Both of these types of lid were precast in advance using a steel mould placed in the area of the casting yard between the two tracks of the Whirley cranes.

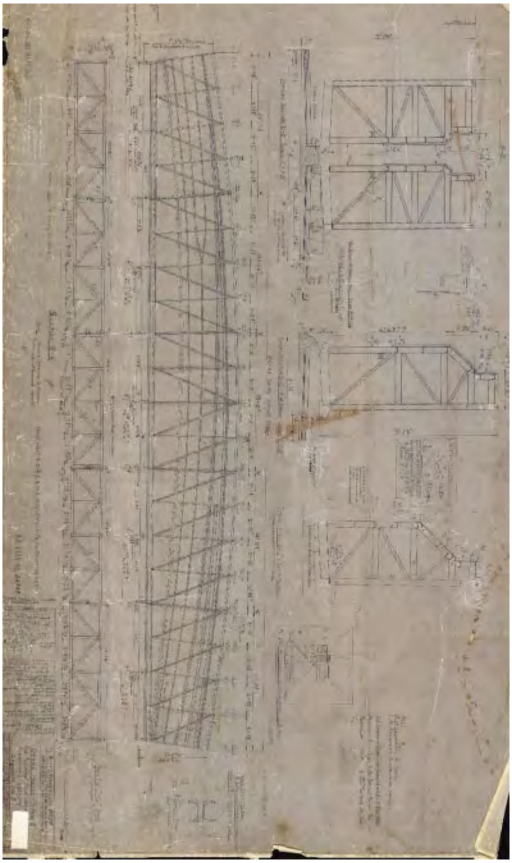

Figure 3. M.R. Hornibrook, Rib Segment Formwork, Section, Frames, Detail, Segments from 1 to 5. NSW Archive and Records. NRS:64328 – 73-20 (revision F).

The formworks for the standard ribs were called beds. On-site, there were eight different beds marked with letters (i.e., A, B, C, D, E, F, G, H,) in the official construction documents. In addition, there were four beds for the octopus arches with varying cross-sections, also marked with a letter (i.e., K, L, M, N).

These beds served for the pour of the sides of the rib and arch segments, connecting the diaphragms and the top-chord lids, and forming the different sub-components into a single piece ready to be cured and then assembled into position.

Each bed was made from three different sections, two steel truss moulds and a central web in concrete (Figures 3–4). The steel forms were finished

Figure 4. M.R. Hornibrook, Rib Segment Formwork, Section, Frames, Detail, Segments from 1 to 5. NSW Archive and Records. NRS: 64329 – 73-21 (revision G).

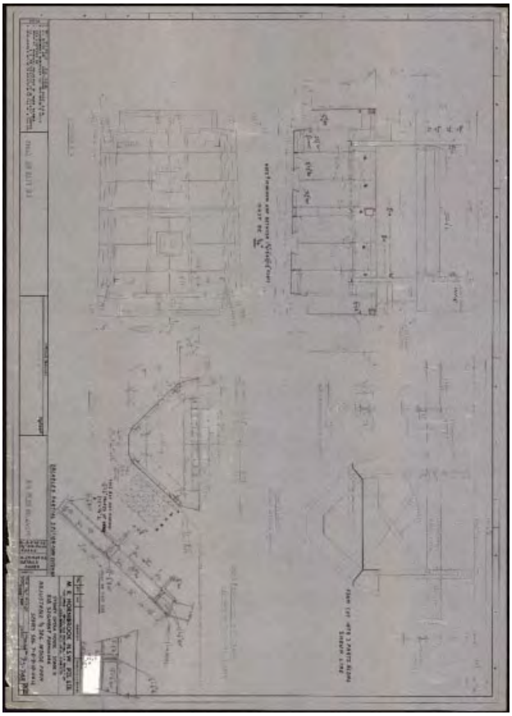

Figure 5. M.R. Hornibrook, Rib segment formwork, internal form (revision A). NSW Archive and Records. NRS: 64586 – 73–749.

with plywood of one and one-eighth of an inch. The plywood had a covering of polyester fibre, which gave the concrete an extremely smooth coat. The two sides of the bed were moveable. The steel supports were positioned on tracks which moved in and out over about one foot and were operated hydraulically. The centre concrete wall was permanently fixed and simulated the constant curve of the shell roofs, which were calculated on a radius of 246 feet, eight-and-a-half inches. This central wall acted as the mould for the lowest ceiling point of the cross-rib section, while the truss-side structures changed to accommodate the variation of the rib section. The top of the bed-trusses was completed with a timber walk board, allowing the builders to walk around to manage the different tasks.

The length of the first segment poured into a bed was determined by the position of the concrete bulkhead diaphragm which was placed into the formwork before the pouring of the segment. The reinforcement bars for the segments were folded and assembled in timber cradles and lifted into position in the bed by the Whirley crane. On the side of the bulkhead on which the segment was poured, reinforcing rods were fixed to the diaphragm. These ensured the binding of the bulkhead to the segment in one composite mass. On the other side of the bulkhead, where the second segment was poured, two steel spigots were fixed. The holes the two spigots left in the second segment enabled it to be exactly positioned during the erection. A separating agent was applied, ensuring that the second segment did not become bonded to the bulkhead. Further segments were similarly poured. These first phases focused on fabricating the bottom chord of the rib sections connecting to the diaphragms, which also acted to contain the concrete poured along the length of the bed. For the formwork of the rib sections with the Y-shape, an internal formwork was necessary to cast the side of the components (Figures 5–6). This internal formwork was fixed as a hat on top of the bed section after the reinforcement cage was placed (Figure 7). After the sides and the bottom chord of the rib section was constructed, the precast top-chord lid (often the cross-bracing) was position on the top. A final pouring phase bound the top chord with the rest of the concrete block already cast in the bed. After the final cast, the segments were to be removed from the beds upon reaching a strength of about 3000 psi (approximately 10 days) and remained in the yard until they reached a strength of 6000 psi (approximately 28 days). Before removal of the segments, the two sides of the soffit were hydraulically rolled out to open up the whole formwork system. The Whirley crane then

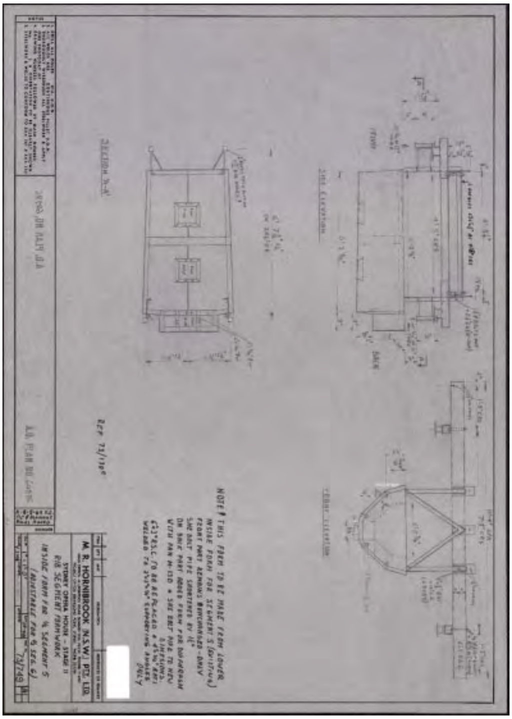

Figure 6. M.R. Hornibrook, Rib Segment Formwork, internal form (revision B). NSW Archive and Records. NRS: 64585 – 73–748.

Figure 7. Images from the documentary *Jørn Utzon: The Man & The Architect* (2018) showing the internal formwork lowered on top of a rib-bed. Courtesy: Sydney Opera House.

removed the segments and transported them to another area of the yard to cure. Hornibrook also designed an ingenious tackle that suspended each segment from the crane in its correct altitude and orientation in space.

Three gangs of workers ensured continuity in this phase of the construction. The first group was dedicated to preparing the formwork, the second group was dedicated to pouring the concrete, and the third gang was focused on stripping the components.

6 CONCLUSION

Succinct though it may be at this point of the research, the story of the for-fabrication works put together on-site at the Sydney Opera House tells a tale of work planning and ingenuity that counterbalances the historical myth of the “eureka” moment of the spherical solution of the sails, by highlighting the amount of labour – intellectual as well as physical – required to materialize Utzon’s great idea.

Without taking anything away from the leap of imagination that led to the solution eventually employed, the actual construction of the sails of the SOH owes a huge debt to Australian know-how, as represented in the work by its general contractor, Hornibrook, and its workforce. Indeed, the spherical solution generated a series of significant construction chain challenges, from task identification to site planning, system engineering to shop drawing preparation, work monitoring to quality control, which were all solved through local contribution. Hornibrook did overcome the technical issues posed by the fabrication of all the different parts required through the production of copious, detailed documentation based on and refined via a long period of prototyping work carried out in Australia. Such documentation will necessarily remain a critical object of analysis and reflection in the continuation of the study. At the present point, however, a provisional conclusion can be attempted on fairly safe grounds: for a building justly considered unique and out of time – and as such worthy of world heritage status – the mundane aspects of its realization and the challenges these raised for the industry at the time may well constitute the true gauge of its “concrete” achievements on the ground.

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Thematic sessions

History of Construction Cultures – Mascarenhas-Mateus & Paula Pires (eds)

Form with no formwork (vault construction with reduced formwork)

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Studies on masonry vault building are often grouped according to materials, trades, or historical periods. This session, however, focuses on a transversal issue – the assembly process itself – by bringing together ongoing research on the relationship between form and the need for formwork in vault construction as a consequence of decisions concerning form, whether it be the general design, the arrangement or bonding or the particular shape of the pieces, as well as the formal control procedures required when there is no supporting centering.

Throughout the history of construction, different materials and arrangements have been used to reduce formwork in vault construction. We know of examples of “false vaults” from as early as the 13th century BC, in Mycenae. These have successive horizontal projections that do not need formwork thanks to their horizontal bed arrangement. Nubian adobe vaults and later brick vaults by slices in Byzantium did not need formwork due to the use of ingenious arrangements. And we know that such vaults were used until the 20th century in Spain, and that the tradition is still alive today in Iran and especially in Mexico. Choisy focused for the first time on the constructive advantages and reduction of formwork of Byzantine vaults; in addition, he proposed that the internal brick ribs in Roman concrete vaults had the main function of lightening the formwork.

The material is also key in the absence of formwork in tile vault construction, with a first layer laid with plaster, or in the support systems using precast plaster plates as light formwork for masonry vaults construction, which could have been in use back in the early days of the Sassanid Empire. Gothic and Renaissance springings, built by horizontal beds, do not need formwork either. Likewise, the Gothic web may not require supporting formwork if it is made of unique stone pieces within a dense rib network, or of tile vaults or brick by slices.

Papers included in this session deal with various aspects of brick construction with no formwork, which is achieved by arranging the brick vertically or slightly inclined (vaults by slices) or flat (tile vaults) (see Figure). They address the study of relevant cases and trace the diffusion of the techniques.

Vitti reviews the oldest cases in the Mediterranean basin, pointing out the use of brick vaults by slices, vertical or inclined, in the Peloponnese in the 1st and 2nd centuries, introduced by Roman builders.

Almagro delves into the origin of tile vaults, whose oldest example was so far located in Valencia dating to the 14th century. He also studies two cases in Iran, one of them from the 11th century, which could constitute the earliest known example of this technique.

Rabasa, Gil-Crespo, González-Uriel and Sanjurjo have studied the geographical and chronological extension of brick vaults by slices, from Byzantium to the present day; they have carried out a comprehensive review of this type of vaults, determining dating, location and constructive configurations, and they have reflected on the diffusion of this technique (Fig. 1).

Rosado addresses the study of a large sample of 110 tile vaults in southern Portugal traditional housing from the late 16th-17th centuries, allowing a comparative and global analysis. The work gives a new point of view on the constructive systems used in housing architecture.

Murphy, Michiels and Trelstad show how formwork was used in some Guastavino tile vaultings, based on historical photographs, and its relationship with the mortar type, based on petrographic analysis. When they had a heavy formwork, Portland cement mortar was used, because no quick-setting was needed. If a light formwork was used, a gypsum mortar was selected.

Figure 1. Main brick arrangements in a barrel vault: from left to right, radial brick, tile vault and vault by slices (Rabasa 2020).

History of Construction Cultures – Mascarenhas-Mateus & Paula Pires (eds)
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Understanding the culture of building expertise in situations of uncertainty (Middle Age-Modern times)

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1 DESCRIPTION OF THE TOPIC

In the building domain, only the three most common actors working in the art of building – contractors, architects, and engineers – have been the subject of ongoing study. While these figures deserve considerably more research, the expert, or surveyor, is still widely unknown. And we must not overlook the role played by another player involved in the act of building – the client or financial sponsor – who is entirely neglected by historians. These players are supposed to assist decision-making in an atmosphere of uncertainty. Their advice may be evaluative of a past or present situation, even predictive (to solve a crisis situation) or preventive (to avoid a disaster).

Experts serving as superior authorities gave their advice on situations either out of court, to appraise a piece of heritage or work, or before a court in the case of a trial between two or more parties. In the latter case, experts would assist the judge, who was not, *a priori*, a building specialist but was nonetheless required to hand down decisions in the sphere. The tasks given to experts took three different forms: technical (to assess the quality of materials, a building process or proceedings at the building site); economic (to give an estimate of a building as part of an estate, the cost of work to a building, or to approve the amount of wages or architect's fees); and legal (to check whether a building complied with official construction, architectural and urban regulations, particularly in relation to alignment and easements).

In France, experts were members of building trades only. Every local area had an elite corps that was more learned than the other members of their community. Initially, they were elected by their peers and described as *jurés*, or "sworn" experts. By the 16th century, after their specific skills had been assessed, they had to acquire an "office" from the King. In 1690, this corps was officially divided into two sections: one of "bourgeois" architects, the other of contractors. However, the invention of experts in other professions with no official statute, such as architects or engineers, is in need of clarification. How did contractors, architects and engineers distribute their activities between building and surveying? Was expertise a way to gain access to architectural patronage? Did experts play a key role in the normalization and theorization of building rules through treaties and handbooks? Were they involved in building innovation? Insights could be gained from analysing experts as a community, according to their expert work, their overall functions, their social networks (family, sponsorship, partnership, clients), or wealth (financial activity, assets). Though we are beginning to discover their statutes in France, we do not have a precise understanding of their real practice and know nothing about their statutes and importance outside that country. We wish to gather contributions on building experts and expertise in different European countries, as well as in countries from different continents, over a long or short time period. This initiative should enable us to draw broad comparisons between the statutes, tasks and practices of different types of building experts, revealing their similarities and differences. This would bring to light the different kinds of sources that can be used to draft a history of expertise.

2 RELEVANCE OF THE TOPIC

The question of building experts and expertise is particularly relevant for a session at the 7ICCH because of its interdisciplinary approach, comparative method and continuity throughout history. What better occasion than an international congress to discuss

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the recurring, national function of building expertise all around the world? If the medieval and Latin model is well-known, what about the English system of surveyors through the Royal Institution of the Chartered Surveyors (RICS)? What is the connection between this famous institution and the London Viewer's reports? Were engineers much more involved in assessment than contractors or architects in 19th-century Germany, or in the USA? An overview of the various urban and rural situations subject to expertise, as well as of the different statutes of experts, could be enlightening.

The question of expertise plays a prominent role in contemporary society. All major societal issues require a wealth of expertise. As such, the figure of the expert has been subject to much criticism since the 1980s because, beyond his/her competence, he/she may appear to be partial or a partisan, corrupted by conflicts of interest. New kinds of experts – such as inhabitants – seem to emerge in urban planning for the regulation of cities. New modalities of expertise from Scandinavian countries are being tested (e.g. citizens' conferences), and above all a new legal statute for the expert is being created in Europe for whistleblowers.

Finally, in the field of construction, many different trades work on the site itself and many specific experts are required for each trade. Is the mason, architect or engineer sufficiently competent to play the part of expert in each building activity (carpentry, tilling, joinery etc.)? Though each building trade supplies specific experts, the three leading trades should concentrate all knowledge relating to the art of building. These three reasons warrant the organization of a special session on experts and expertise during the 7ICCH.

3 SESSION CONTENT

Sandra M. G. Pinto examines a Portuguese institution, the *vedor* of works of the city of Lisbon, over the long term (14th-19th centuries). This occupation, which she describes as that of a building expert, was never held by a contractor, architect or engineer. She tries to understand how a profession whose duties revolved around the administration of public building contracts could be used to manage and monitor both the technical and accounting aspects of public works. While this profession became hereditary in 1560, it had above all an urban political role. In order to achieve its aims, it was probably at the head of an administration composed of assistants highly qualified in construction matters.

Barbot, Carvais, Château-Dutier and Négre relate how in Paris in early modern times, private construction expertise was entrusted to a specialized group, half contractors and half architects. In addition to the litigation activity, which focused on neighborhood and partition matters, and the assessments of the value of movable and, above all, immovable property, it was repair and maintenance activity that attracted the French team. The authors demonstrate how this repair activity (which accounts for nearly 30% of the expert role in Paris) has a decisive impact on technical activity (description of damage, analysis of causes, vocabulary, chosen solutions), on economic activity (impact of repairs and maintenance on the value of property, action of repairing as the center of strategic economic rationality), and on the application of customary law (nature of repairs and burden of their costs), and even beyond (repairs can also be used as a pretext for "heritage" conservation interventions).

Libby Cook analyses the maintenance of public buildings in 19th-century Virginia (USA). This construction activity involves an authority, operators and users. At no time is there intervention from specialists in decision support and control of the work carried out, such as experts. Yet there are continual financial conflicts between the decision-makers, who always plan at a minimum, and the contractors, who are paid late. Throughout the article, we perceive the need for the intervention of disinterested people, independent, impartial arbiters between the actors of the maintenance works. This study is based on three case studies of three emblematic buildings of American democracy: the replacement of the Governor's residence whose state of repair had become unacceptable; the repairs of the Virginia State Capitol; and the renovation of the State Armory.

Jelena Dobbels studies the settlement of construction disputes through a batch of 48 cases in which expert opinions were requested and kept in the archives of the Brussels Commercial Court between 1957 and 1959. Depending on the roles played by the parties on the building site and the person bringing the case before the court, the client, the building actors and the numerous alternatives a typology of conflicts associated with specific causes can be established: damages and the responsibility of the parties involved, disrespect for the rules of the art, or financial deviations. The scenarios explored show dysfunctions in the classic triangular relationship (client, contractor, architect), systematically excluding the engineers (perhaps conditioned by the sources of research). The history of experts shows a strong link with their professional associations. Knowing that the initial task of the Belgian experts was to try to find a compromise at all times, we would be curious to learn what happened to the expertise on the judge's desk – if anything.

History of Construction Cultures – Mascarenhas-Mateus & Paula Pires (eds)

Historical timber constructions between regional tradition and supra-regional influences

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Culturally and regionally specific construction methods are rarely as pronounced as in historical timber construction. But even in the Middle Ages, essential construction elements were already similar in regions that were separated at least by political borders. At that time, the wanderings of builders helped the spread of various construction methods and building traditions. Builders also often developed region-specific skills that respond to local characteristics. Bridge construction and hydraulic engineering, for example, reached great maturity where they were in particularly high demand. Climatic conditions have caused the same construction tasks to be carried out very differently from region to region. With the beginning of the early modern era, the first efforts to communicate the construction methods that had proven themselves in many places in the past found a new medium: the treatise. Notably, in the 18th and 19th centuries examples of constructions typical in a region were drawn and published in numerous specialist books alongside constructions that followed scientific findings or theories. For this thematic session, valuable contributions were submitted that address the range of these influences on timber construction and more.

The series begins chronologically in the far north. R. Gullbrandson and M. Hallgren discuss how a hybrid type of roof construction developed in the 12th century in western Sweden. In Central Europe, Italian influences played an important role in the early modern period. This also applies to timber floors, which today are simply linked to the name Serlio, but in fact have had a much more complex evolution. E. Zamperini shows that such constructions were already discussed in medieval France and became much more popular in literature than in reality. The contribution by L. Guradigli and G. Mochi proves that mutual influences have of course also taken place within Italy and its numerous small states. I. Engelmann explains why some types of construction proved themselves very durable and resistant to influences in certain regions, with reference to bell frames in Switzerland and Thuringia. Bridge construction requires highly specialized skills. P. S. C. Caston shows us that this expertise was not available everywhere and therefore had to be sought from far away. He also demonstrates the influence of model-making on the construction of bridges. K. Russnaik describes how, beyond the treatise, the place a master builder was educated could also have a significant influence on the appearance of constructions in the 19th century. Treatises also played a role in the spread of de l'Orme's roof constructions in the Netherlands. However, the selection of constructions also had a political component, argues E. D. Orsel.

Thanks to the participants, the session fulfills 7ICCH's aim "to celebrate and expand our understanding of the ways that everyday building activities have been perceived and experienced in different cultures, times and places".

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History of Construction Cultures – Mascarenhas-Mateus & Paula Pires (eds)

Historicizing material properties: Between technological and cultural history

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While no one could sensibly deny the importance of materials for architecture, they have long occupied an only marginal position within the discipline of architectural history and theory. Confronted, however, with the limited resources of planet Earth, scholars have increasingly started to point to the importance of material histories of architecture. As Katie Lloyd Thomas argued in the aptly titled *Material Matters*, this historization of building materials is crucial for architecture to "reach an understanding of how materials may be productive of effects, both experiential and political". All the more important now that popular descriptors for building materials – like *durable*, *sustainable* or *ecological* – are continually used without any historical awareness of the (at times disturbing) contexts that engendered these categories. By analysing the discursive practices in which building materials are mobilized, and the tense "moral economies" that underlie such practices, the papers collected here aim to respond to Antoine Picon's provocative question, "What does it mean [for a building material] to be hard, waterproof or durable?"

Susanne Brunner's research into transparent acrylic constructions immediately highlights how the iconography of new constructive methods and production processes discussed in her paper can serve varying and shifting economic or political agendas. In interwar Germany, the use of transparent polymers in car design and the building industry was deployed in national propaganda to showcase the national technological prowess of the National Socialist regime. However, in architectural flagship projects such as the Munich Olympic sports facility acrylics were used to promote the contrasting ideals of Germany's postwar democracy.

Recent work by Simon De Nys-Ketels and Robby Fivez on the architectural histories of the former Belgian Congo suggests that such political mobilizations of building materials were especially common in colonial contexts (although of course not limited to them). Remarkably, the first decree that sowed the seeds of the segregationist spatial politics in the Belgian Congo, was in fact a law on building materials. It divided colonial cities into quarters reserved for wood and iron constructions", and "another for *huttes, paillotes et chimbèques* [three different local construction techniques]", shrouding political aims of segregation in a constructive terminology.

Excepting the German case, the papers presented here highlight how colonial power relations were enacted through building materials, demonstrating that such stark discursive distortions might indeed surface in their crudest form in the political and cultural context of colonialism. L. Mendonça's analysis describes the deployment by the Portuguese colonial authorities in Mozambique of a classification of building materials to implement urban racial segregation in the capital of Lourenço. Marques suggests that such government strategies transcended across colonial borders. Nic Coetzer's inquiry into the introduction of the Arts and Crafts movement in South Africa reveals that racial hierarchies of materiality also pervaded architectural discourse. Although the Cape Dutch style – the vernacular architecture of the European settler community – deployed the same mud and thatch materials as those utilized in "native" hut architectures, the former was praised in contemporary architectural debates while the latter was scoffed aside as an inferior form of building.

Spanning building details, product design, architectural design decisions, mediatized landmark projects and urban planning, these papers together reveal how historicizing the socio-cultural, economic or political dimensions of building material requires cutting across multiple scales and sites. This is confirmed in the final two papers. In their comparative analysis of brick construction in the 15th century, Esteban Prieto-Vicioso and Virginia Flores-Sasso cross multiple production sites, highlighting homogeneous production qualities that implicitly served the colonization of the New World. Jessica Garcia Fritz's analysis of architectural specifications as an administrative instrument in the emerging building sector of 19th-century America further develops these insights. By privileging white pine as the prime construction material, these specifications boosted the emergence of sawmills across territories that had officially been attributed to American indigenous tribes. In this way, political agendas of colonization are served not only by discourses regarding the physical properties of building materials, but also by their production processes.

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History of Construction Cultures – Mascarenhas-Mateus & Paula Pires (eds)

South-South cooperation and non-alignment in the construction world, 1950s–1980s

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Recent scholarship in both construction history and architectural history has experienced an increasingly clear transnational turn in perspective where narratives of the global circulation of expertise, materials and processes are superseding previous discourses that centered on the agency of individual actors, projects or states. Beyond the mere technical and material dimensions of construction, focus on the transnational transfer of construction systems and processes is further demonstrating how the building world is a particularly revealing lens for critical inquiry into the political and economic dimensions of globalization and international development in recent history. Bound by the assumptions of a history of technological progress, however, contributions to this emerging new narrative are still limited in many cases by the epistemic hierarchies that continue to privilege frameworks of power and knowledge transfer from the developed to the developing nations that were framed in earlier colonial-modern processes of economic and cultural imperialism.

Building upon the chairs' multi-disciplinary grounding across architecture, construction and social history and our previous thematic session (6ICCH Brussels) – which examined multi-lateral exchanges of materials, processes and construction knowledge in the building worlds of 19th- and 20th⁻ century Asia – the present session sought to extend that trans-regional perspective to the broader "Global South" that emerged, as we know it today, in the second half of the 20th century. Addressing patterns and processes of exchange within the internal networks of this wide geo-political community of ex-colonial states, we aimed to further the development of a more heterogeneous genealogy of the globalizing construction world, focusing specifically on transfers that simultaneously resisted the latent interests of former colonial powers whilst subverting the emerging new imperial hegemonies of the Cold War superpowers.

While South-South exchanges of materials and technologies long predated the colonial era, patterns of cooperation between nations of the contemporary Global South are intimately tied to the new world economic order promoted by the Non-Aligned Movement (NAM) and Group of 77 (G-77). Formally institutionalized in Belgrade, Yugoslavia in 1961, the NAM had, since the early 1950s, been an operative and increasingly compelling ideal of self-help and solidarity between newly de-colonizing nations that sought to resist political and economic dependency in the context of the Cold War. The G-77, formed just three years later in 1964, served to articulate the collective interest of the majority block of poorer emerging states within the United Nations. The subsequent focus on Economic and Technical Cooperation among Developing Countries (ECDC/TCDC) allowed for further fruitful exchange, not least within the construction worlds of the Global South.

The five papers ultimately selected for this session illuminate the broad geographic scope of these developments, as well as a range of different case material, scales and relevant methods of interpretation. In the first of two case studies exploring the transnational exchange of construction knowledge and services emanating from Yugoslavia – a key NAM player – Jelica Jovanovic charts the remarkable trajectory and translation of the Žeželj system for concrete prefabrication and assembly from its development in postwar Yugoslavia in the 1950s to post-revolutionary Cuba in the 1960s, and onward to post-colonial Angola in the 1970s. Luka Skansi's following study, with Jelica Jovanovic, of Yugoslav bridge-building in Iraq in the 1960s further illustrates the significance of construction as one of the more substantive modes through which the NAM member countries attempted to sustain political and economic independence through technical cooperation.

Marwa El-Ashmouni offers further insight into the case of Iraq in a paper that outlines the wide-ranging engagement of building and planning professionals from Egypt, another NAM leader, in the modernization of other near neighbours in the North African and Middle-Eastern region. The paper traces the agency of previously unsung players within the governmental and professional design and construction networks who, having gained technical proficiency through initial collaborations with first- and second-world-aided AEC mega-projects such as the Aswan

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Dam, subsequently enabled increasingly autonomous transfers of technology and expertise on their own terms.

The Middle East and its profound inter-connections with the material, technical and human resources of India – yet another key exponent of the NAM – and its building world are the focus of the final two papers. Shaji Panicker offers an ethnographically rich glimpse into the recent construction history of the Arab/Persian Gulf states from the perspective of individual members of the professional and entrepreneurial sub-cultures of South Asian migrants whose instrumental background roles in the procurement and delivery of construction materials and systems has underpinned this extraordinarily dynamic building culture. Finally, Vandini Mehta and Rohit Raj Mehndiratta provide fascinating original insight into the archive and practice history of structural engineer, Mahendra Raj, one of the most significant actors in the construction history of modern India. Raj's substantial work on major projects in Iran and other Gulf states in the 1970s was a medium of technical cooperation and exchange with evident impact on later construction norms and practices in both India and the Middle-East that has not previously been examined.

Looking beyond the individual and institutional archives, the oral histories, and the built artefacts and infrastructures that have specifically informed this set of exploratory papers, it is abundantly apparent that the greater archive of the construction history of the Global South has only just begun to be opened. Further research into the "constructive" built and systemic legacies of technical cooperation and Non-Alignment in the geo-political struggles of the recent past would appear to be a particularly rich vein on which to sustain focus.

History of Construction Cultures – Mascarenhas-Mateus & Paula Pires (eds)

Construction cultures of the recent past: Building materials and building techniques 1950–2000

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With this thematic session we set out to gain insight into building practice and construction culture 1950–2000 by examining both innovative and pioneering experiments, as well as day-to-day building practice based on typical, common and traditional building materials and techniques. We aim not only to understand the technical and material properties of these materials and their applications, but also to link these technical aspects with cultural properties to discern how building culture is embedded in building materials. Additionally, we intend to capture the tension and interaction between global developments and local applications of particular building materials to encourage an intercultural perspective.

While in the call for papers for this thematic session we originally stated that the period 1950–2000 is far from fully explored within construction history – in particular in relation to the threefold aspiration we put forward – the number of abstracts and papers that were submitted for this session by far exceeded our expectations. The papers covered a multitude of topics, materials, practices, contexts, professions and actors: a demonstration of the increased scholarly interest in this theme.

The papers that are presented here all deal with particular aspects of the broader theme. We selected two papers that focus on glass and glazing: the scope and approach of each is different and complementary to the other. One is an in-depth study into the development and application of a particular brand of reflective glazing (paper by Alison Inglisa), while the second takes a broader viewpoint, showing how developments and solutions in the field of insulating glass indicate the changing relationship between the construction sector and the environment, with a sometimes paradoxical result (paper by Jean Souviron). Two other papers investigate the relationship between material culture and the socio-economic context. The paper by Francesca Albani deals with precast reinforced concrete: although the material was ubiquitous at that time, the paper shows how the technique was customized to the local context, conforming to the motivations and intentions of the actors involved. Another aspect of the relation between material culture and the socio-economic context is examined by Alison Creba and Jane Hutton. They demonstrate how the status and quality requirements of materials change in the transformation from building material to building waste and back. The fifth paper in this session, from Maris Mändel, addresses the interaction between the local and the global by looking into how building culture is transformed when (international) building materials suddenly become available on the local market.

These five papers do not intend to sketch a complete or representative image of the wide range of materials available in the period 1950–2000, or of the various ways in which they were applied, or indeed the particular contexts in which they were developed and assimilated. Rather, in combination with the papers that fall within the other sessions, the collected papers can be considered a *pars pro toto* for recent research topics, angles and directions. In that sense, by virtue of its threefold ambition, the session thus also strives to contribute to the further development of construction history as a discipline. Furthermore, the accumulated knowledge herein will provide new insights and enable cross-pollinations in other domains, especially those disciplines for which the research period 1950–2000 is (also) largely unexplored or which can benefit from the typical interdisciplinary approach within construction history, such as architectural history, heritage studies, architectural renovations and circular (re)construction.

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Hypar concrete shells: A structural, geometric and constructive revolution in the mid-20th century

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This thematic session focuses on the construction of shells made of hyperbolic paraboloid (hypar) surfaces, which had their zenith in the 1950s and 1960s. The aim is to study in depth the various aspects that characterize and define this type of laminated reinforced concrete structure (which offered extreme efficiency given the advantageous structural characteristics of the hypar geometric form), and the conditions that determined its development and diffusion. Analysing and contrasting different points of view gives a panoramic view of one of the most surprising construction phenomena of the last century. Participants presented studies on hypar concrete shell structures that address the analysis of relevant aspects in their construction, under the following approaches:

- Analysis methods employed: Everyone who builds must be able to guarantee the safety of the work done. This has been a permanent need in all types of construction. The introduction, development and diffusion of any construction technique must be linked to the knowledge of its behaviour, according to the means available at any given time, and to the capacity to demonstrate its safety. The study of the methods of analysis used in each place and at each time stems from these concerns.
- Experimental studies: Reduced models. Analytical knowledge of the behaviour of shells usually led to inaccessible numerical solutions. As an alternative and support, some technicians developed tests on scale models to demonstrate the sufficient strength and rigidity of the structures, as well as the structural advantages offered by the hypar's geometry.
- Construction methods and materials used: Essentially, shells were made of reinforced concrete poured over continuous formworks. However, other materials and techniques were also explored, giving rise to local solutions that reached significant levels of development and resulted in remarkable works.
- Relationship with the economic and social conditions: One of the fundamental aspects in understanding the emergence and success of a construction process is to understand the influence of the technical and economic conditions of the environment in which it takes place.
- New materials and new techniques: The designers and builders of shells were faced with a new technique in which they were forced to reuse the techniques they had at their disposal and add their own contributions to simplify and improve the final result. These investigations gave rise to different procedures (formworks, scaffolding, prefabricated moulds, sprayed concrete) or materials (concrete of different qualities, pre-stressed sheets, concrete with fibres, plastics, etc.).

Of course, the five approaches we describe do not limit the field of study, but they give an idea of the extent of the topic proposed.

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History of Construction Cultures – Mascarenhas-Mateus & Paula Pires (eds)

Can engineering culture be improved by construction history?

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LACK OF CONSTRUCTION HISTORY IN THE EDUCATION OF CIVIL ENGINEERS

Contemporary engineering education rarely includes construction history in the curriculum, and if it does it is either an optional module or a side note, while architectural history is considered a necessity in the education of architects. This can result in a lack of awareness among engineers of their own profession's history, an entirely uncultured approach towards existing and historical structures, and the inability to draw inspiration from or critically interpret the work of past or even contemporary builders.

Within this context, this session includes papers and presentations to highlight (1) how construction history is a key tool to promote a more passionate, conscious and cultivated engineering profession; (2) case studies where the contribution of engineering to preserve the historical heritage was highly relevant; and (3) case studies where the knowledge of history was important because it provided significant information or inspiration for a modern construction.

KNOWLEDGE OF CONSTRUCTION HISTORY AS A WAY TO IMPROVE THE WAY ENGINEERS WORK

Climate change is forcing humanity to build more sustainably. Maintaining and adapting existing structures (buildings, bridges, etc.) for them to continue to be used – e.g. for a different use or stronger loads – is an inherently sustainable goal which, unfortunately, is often ruled out as a concept by engineers and owners since a replacement structure seems more economic.

Educating engineering students and practitioners in construction history and raising awareness in the engineering community of the cultural value of historical structures could help alleviate this by improving awareness and respect for what has been designed and built by preceding generations of engineers. Furthermore, it could improve the understanding of the materials and processes that were used to create these structures, making it easier to maintain and adapt them economically.

It is the session chairs' hope that this thematic session will contribute in some measure to the goal of making civil and structural engineers accept construction history as a valuable tool in their everyday work.

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