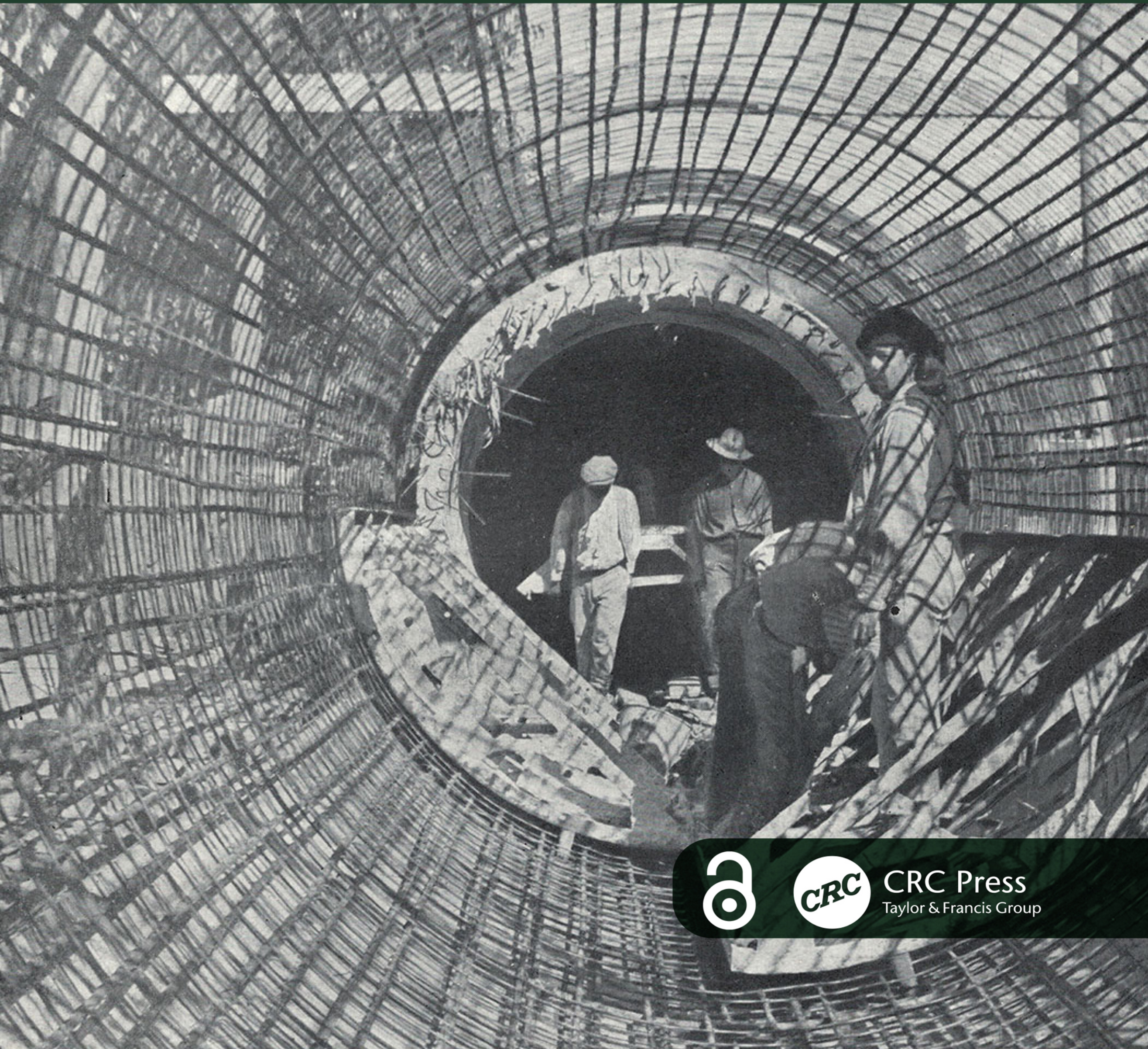
Changing Cultures

European Perspectives on the History of Portland Cement and Reinforced Concrete, 19th and 20th Centuries

Edited by

João Mascarenhas-Mateus



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The construction practices we employ in our daily life in European societies today were shaped by major changes in the past, such as the introduction and dissemination of Portland cement and reinforced concrete, a development that constitutes a fundamental chapter in the history of construction in the 19th and 20th centuries. Such changes were boosted by several innovations in the fields of applied mathematics, chemistry and physics. They involved patents licensing, optimization of materials production and machinery. There were new legislative frameworks, a specific knowledge transfer within a network of actors and the transformation of hierarchical frameworks.

Written by international specialists, this two-part book is centred on case studies from the UK, Germany, Switzerland, France, Belgium, Portugal, Spain and Italy. The first part explores the mutual international influence between these countries and their intrinsic characteristics in this field, resulting from each nation's particular economic, social, political, cultural and technological conditions. The second part focuses on the history of public works companies. Capable of carrying out both private works and major infrastructures, these players exemplify the technological and business advances that the construction sector has experienced over the last two centuries. This book is a must-read for researchers on contemporary construction history in Europe.

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Boca Raton London New York

CRC Press is an imprint of the
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A BALKEMA BOOK

Designed cover image: Tagus River Aqueduct. Reinforcement steel bars and internal formwork for the cast-in-place concrete pipeline in an elevated section. [ALVES, J.C. (1948). "Águas de Lisboa" In Número Comemorativo do Boletim da Comissão de Fiscalização das Águas de Lisboa. Exposição de Obras Públicas Maio de 1948. (Lisbon: Imprensa Portugal-Brasil), 15–24.]

First published 2023
by CRC Press/Balkema
Schipholweg 107C, 2316 XC Leiden, The Netherlands
e-mail: enquiries@taylorandfrancis.com
www.routledge.com – www.taylorandfrancis.com

CRC Press/Balkema is an imprint of the Taylor & Francis Group, an informa business

This work is financed by national funds through FCT – Fundação para a Ciência e a Tecnologia, I.P., under the Strategic Project with the reference PTDC/ART-DAQ/28984/2017.

ISBN: 978-1-032-43735-4 (hbk)
ISBN: 978-1-032-43738-5 (pbk)
ISBN: 978-1-003-36865-6 (ebk)

DOI: 10.1201/9781003368656

Typeset in Times New Roman
by Apex CoVantage, LLC

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João Mascarenhas-Mateus is Principal Researcher at CIAUD, Research Centre for Architecture, Urban Planning and Design, Lisbon School of Architecture, University of Lisbon, Lisbon, Portugal, since 2015. He has earned his degrees of PhD in civil engineering (IST, Technical University of Lisbon, 2001) and MSc in architecture (RLICC, KU Leuven, Belgium, 1992). From 2015 to 2020, he was awarded a research contract of excellence (FCT, Portuguese Research Foundation Researcher). During that time, he directed the research project “From Lime to Portland Cement: Construction History and Building Cultures in Contemporary Portugal” (http://ptbuilds20.fa.ulisboa.pt/). At present, he is leading a project to build a digital knowledge platform for Portugal Construction History, during the 19th and 20th centuries (http://portugalbuilds.org/), also funded by FCT.

In 2010 and 2015, he organized the First and Second Portuguese Conferences on the History of Construction in Portugal. He was one of the coordinators of the Organizing Committee of the First and Second International Congresses on Luso-Brazilian Construction History (2013 and 2016) and the founder (since 2015), former president (2018–2021), and present vice-president of the Portuguese Society for Construction History Studies (SPEHC). He is a member of the editorial committee of the *International Journal of the Construction History Society*. He was the chairman of the Organizing Committee of the 7th International Congress on Construction History (7ICCH, Lisbon 2021).

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Jelle Angillis is a historian with a broad interest in the history of architecture and construction in combination with social and cultural history. Angillis was initially active in the building industry itself. At the University of Antwerp, his doctoral research on building practice in post-war Belgium combines his practical experience of the building industry with insights from historical research. In his research, Angillis mainly focuses on the fact that, besides concrete design, social interaction, labour and many hands have also shaped Belgium's built environment. According to his findings, the design is inseparable from the execution, the materials and people who materialized the drawn line. His publications have focused on the history of public works contractors and Antwerp's post-Second World War construction culture.

Inge Bertels is a Belgium historian and Master in Conservation. Her personal research focuses on the intersection of 19th and 20th century construction history, architectural and urban history. From 2000 to 2006 she was linked to the R. Lemaire International Centre for Conservation and the Architectural History research group of the Department of Architecture, Urbanism and Planning of the Katholieke Universiteit Leuven, where, in April 2008 she successfully defended her PhD "Building the City, Antwerp 1819–1890". Later she worked as a postdoctoral fellow of the Fonds Wetenschappelijk Onderzoek at the Centre of Urban History of the Universiteit Antwerpen, and as a lecturer and researcher at the Department Architectural Engineering of the Vrije Universiteit Brussel. Since February 2018 she has held a full-time position as Full Professor of Architectural History and Building Culture at the Faculteit

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Mike Chrimes is a former Director of Engineering Policy and Innovation at the Institution of Civil Engineers (ICE), United Kingdom. Having been responsible for major public works projects, he has a vast knowledge of management in civil engineering with a particular interest in the use of digital media to provide a global information service to the ICE. He has written and lectured extensively on information services for civil engineers and the history of civil engineering. One of his many subjects of interest is the history of engineering and the work of British engineers in South Asia during the British Raj. He has published many books about his investigations, namely *The Civil Engineers: The Story of the Institution of Civil Engineers and the People Who Made It* and the three-book series published by ICE, London: *The Civil Engineers* (2011), *The Contractors* (2013) and *The Consulting Engineers* (2020), co-authored with Hugh Ferguson.

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Bernard Espion is Professor of Structural Engineering at the Université libre de Bruxelles (ULB), Belgium, where he is also the Director of the Civil Engineering Laboratory. He is a founding member of Construction Histories Brussels, the ULB-Vrije Universiteit Brussels joint research group. His main research interests in Construction History lie in structures (reinforced and prestressed concrete, composite steel-concrete, cable roofs, thin concrete shells, bridges), materials and construction processes (cement and concretes, iron and steel), historical evolution of structural theory and design concepts, especially by Belgian engineers, contractors and companies in the 19th and 20th centuries. He contributes to the promotion of Belgian civil and building engineering heritage with publications, lectures and contributions to exhibitions. He has co-authored innovative books on the history of public works contractors such as *Blaton. Une dynastie de constructeurs / Een dynastie van bouwers* (Brussels: AAM Editions - Archives d’architecture moderne, 2018).

Tullia Iori holds a PhD in Building Engineering: Architecture and Construction with a thesis on the history of reinforced concrete in Italy from its origins to the Second World War (1999). A research fellow (1999–2001) and later researcher (2001–2005) at the Faculty of Engineering of the Università degli Studi di Roma Tor Vergata, Italy, she became associate professor in 2005. She has held the post of Full Professor since 2013, and Coordinator of the single-cycle Master’s degree course in Building Engineering - Architecture at the same university. Since 2014 she is coordinator of the PhD in Civil Engineering. Since 2012 she has been Co-Director of Research for the SIXXI project (ERC Advanced grant 2011 | with Sergio Poretti. The project is dedicated to the History of Italian Structural Engineering in the 20th century. Her research is published in the form of articles in scientific journals and essays in books. With Sergio Poretti she coordinated the five-book series *SIXXI – Storia dell’ingegneria strutturale in Italia* (Rome: Gangemi, 2014–2020).

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(2015), former president (2018–2021), and present Vice-President of the Portuguese Society for Construction History Studies. He is a member of the editorial committee of the International Journal of the Construction History Society. He was the chairman of the Organizing Committee and Proceedings editor of the 7th International Congress on Construction History (7ICCH, Lisbon 2021). Author of several papers in scientific journals, his publications include *Técnicas tradicionais de construção de alvenarias* (Lisbon: Livros Horizonte, 2002) and coordination of the books *História da Construção em Portugal: fundações e alinhamentos* (Coimbra: Almedina, 2011) and *História da Construção em Portugal: consolidação de uma disciplina* (Lisbon: By the Book, 2018).

Michel Provost teaches construction techniques at the Université libre de Bruxelles, Belgium, both at the École polytechnique and at the Faculté d'architecture La Cambre Horta. He is also a consulting engineer in charge of structural studies for several projects in infrastructure, building and heritage. In all these activities, he has always maintained close links with the educational sphere. He has published works on underground structures, on the interaction between structure and architecture (e.g. on the pavilions of the 1958 Brussels World Fair), engineering heritage in Belgium and in the Democratic Republic of Congo during the 19th and 20th centuries. With Bernard Espion and Rika Devos, he was responsible for the highly pioneering and innovative project aimed at the preservation and study of the contractor Blaton's archives (Brussels, 2014–2016).

Gilbert Richaud is an architect and researcher at Laboratoire de Recherche Historique Rhône-Alpes UMR 5190, Lyon, France. His work is focused on the study of the history of concrete during the 18th and 19th centuries. He is author of fundamental books on Antoine Desgodets and François Cointereaux and their vital importance to the development of rammed earth constructions. Richaud has dedicated a great deal of work to the relations between the concrete of Ancient Rome and first modern concrete. He has also studied the architect Gaspard André and his pioneering work in Lyon and Genève during the second half of the 19th century. He is author of reference books on those subjects, including *Palladio and Concrete: Archaeology, Innovation, Legacy* (L'Erma di Bretschneider, 2021) with Louis Cellauro, and was the coordinator of titles such as *Les leçons de la terre: François Cointeraux (1740–1830), professeur d'architecture rurale* (Paris: INHA/ Les Éditions des Cendres, 2016) with Laurent Baridon and Jean-Philippe Garric.

Mario Rinke is a Professor at the Faculteit Ontwerpwetenschappen, University of Antwerp, Belgium. He teaches and researches in the fields of technology and architecture. Genuinely interested in transformation processes between areas of knowledge, materials and institutions, as well as structural thinking, he has specialized in hybrid material concepts, early reinforced concrete and early industrial timber (glulam), but also historical and contemporary concepts of adaptable structures. Trained as a structural engineer, he worked as a design engineer for major offices in London and Zurich and ran his own practice in Zurich for several years. Mario Rinke holds a Diploma-Degree in Civil Engineering from the Bauhaus University Weimar and a PhD from Eidgenössische Technische Hochschule (ETH), in Zurich. He was senior researcher and lecturer at the architecture department of ETH and senior lecturer at the Lucerne University of Applied Sciences and Arts. Currently, parallel to his teaching activity he serves as a member of scientific committees, and as a reviewer for different scientific journals. He is a founding member of the International Association of Structures and Architecture (IASA) and is currently a member of its management board. Apart from the many articles he has produced for scientific journals and book chapters, Mario Rinke has edited and co-edited several books, including *The Bones of Architecture: Structure and Design Practices* (Zurich: Triest Verlag, 2019).

Edwin Trout is Manager of information Services at The Concrete Society (United Kingdom) and previously at the British Cement Association. He has acted as Executive Officer of the Institute of Concrete Technology (ICT) since 2011. He has a special interest in the history of Portland cement and concrete industries. His book *Some Writers on Concrete: The Literature of Reinforced Concrete, 1897–1935* published in 2013 by Whittles Publishing, Scotland, traces the emergence and development of the specialist book on concrete, at a time when reinforced concrete was a new technology. Edwin Trout has written widely on the history of institutions and individual actors involved in the cement and concrete industries in many different scientific journals, and contributes regularly with a column to *Concrete*, the Concrete Society magazine.

Ivo Veiga (PhD, University College London, 2012) is a social science and history researcher with interests in democratization, history of construction, digital humanities and societal and political transformations. Veiga is the author, co-author and co-editor of several books and articles related to democratization, political institutions, and their actors, namely *Mulheres e Eleições* (Coimbra: Almedina, 2019) and *Os Constituintes* (Lisbon: Assembleia da República, 2020). He has delivered papers at national and international meetings organized by leading institutions in their fields. Veiga employs several methods to examine different research problems and puzzles: social network analysis, quantitative and qualitative textual analysis, and digital humanities tools. He was awarded with the Marie Sklodowska-Curie Actions Seal of Excellence (European Commission, 2017). As a contracted member of the research project PTBuilds19_20 he co-authored the paper "Portugal Builds: uma plataforma digital para a história da construção em Portugal nos séculos XIX e XX", published in the journal *Estudos Históricos* (Rio de Janeiro: Fundação Getúlio Vargas, 2020).

Introduction

João Mascarenhas-Mateus

In 1909, the book *Reinforced Concrete in Europe* by Albert Ladd Colby (1860–1924) was published with the aim of disseminating in the USA the advances in reinforced concrete made in each of the European countries at that time. Besides introducing the main systems, types of reinforcement bars and their applications, the work describes an intermediate phase of a paradigm shift in the constructive cultures of the Old Continent in which the institutions capable of establishing consensual rules of use for the new construction culture became recognized and – importantly – the first national codes on reinforced concrete construction and the introduction of Portland cement were produced. Since the publication of that essay, several fundamental works have been published on the history of Portland cement and reinforced concrete in the fields of architectural history, art history or history of technology, such as *Concrete: The Vision of a New Architecture* (1959) by Peter Collins (1920–1981); *Le Béton, Histoire d'un Matériau. Économie, Technique, Architecture* (2005) by Cyrille Simonnet (1952–); *Concrete from Archeology to Invention (1700–1769)* published in 2013 by Roberto Gargiani (1956–); or more recently, *German Concrete. The Science of Cement from Trass to Portland, 1819–1877* by Salvatore Aprea, published in 2016.

Today, at a time when reinforced concrete already firmly belongs to a globalized construction tradition, it seems pertinent to focus on the ontology of this culture in Europe, broadening the discussion beyond the authors of inventions, patent owners, structural theorists and rationalist architects from France, Great Britain and Germany, who were revered in the aforementioned books. How did the advent of reinforced concrete manage to diminish the use of millenary cultures of masonry, carpentry and rammed earth to such reduced proportions? What were its origins, and why was this new culture adopted by European countries? The main objective of this book is to reflect on these questions and contribute to answering them. Specialists from different European countries besides Portugal (Spain, France, UK, Belgium, Switzerland, Germany and Italy) were invited to take part in the endeavour to produce a critical reading of this shift paradigm in their own countries. This exercise in critical analysis is framed not in architectural history or the history of technology but within the study of the history of construction, understood as the history of building cultures – in other words, the history of everyday life in communities in relation to the activity of building.

The ways in which we build today in Europe and around the globe result from a cultural paradigm shift initiated with scientific innovations that proliferated during the Enlightenment, accelerated by the dynamics of the industrial revolution, the advent of steam power and steel in construction, and the study, application, testing, refinement and regulation of Portland cement. This process was articulated within a network of actors, which was not limited to patent inventors, academics, engineers and architects; rather, individual and collective contractors,

DOI: 10.1201/9781003368656-1

construction materials manufacturing and resale companies, and public administration institutions also made a fundamental contribution to this change. For this reason, to address more deeply the intricate relationships that were established between networks of actors, this book is divided into two parts.

In the first part, the transformations of the construction cultures of each country are studied from different perspectives: patent registration; administrative policies; knowledge transfer, and in particular the training of engineers and architects; machinery; corporate organization of actors; dissemination aimed at the general public and specialized publications for academics and technicians; and local, regional and national legislative regulations.

The second part analyses the historical paths of different public works construction companies that contributed to the reception, development and projection of reinforced concrete in the UK and Ireland, Portugal, Belgium and Italy as well as in many of the regions under the colonial administration of these countries, extending the geographical scope of the influence of the new construction culture to other countries, especially on the African continent. These national actors, who often had impressive international profiles, have thus far been little studied. Yet they were fundamental to the consolidation and dissemination of new ways of building, starting with early models emerging in France and the UK.

The book begins and ends with texts on the case of Portugal, a peripheral nation situated on the western edge of the European continent with an intermittent capacity for technological updating (due to its geostrategic position and the transformations in its political regimes) that has nevertheless received, processed and adapted reinforced concrete in its daily constructive activity.

Thus, Chapter 1.1, by João Mascarenhas-Mateus, gives a broad overview of the cultural, commercial, economic, academic, legislative and institutional spheres that reflected this paradigm shift in Portugal. The period of study starts in the second half of the 19th century, with the first national activity to produce artificial hydraulic limes and natural cements and the importation of Portland cement. The analysis takes in the discussion in specialized journals and monographs on the limits and the advantages of the new construction process to understand how an excellent consensual reputation for reinforced concrete was created. It concludes with the year 1935, when the second national reinforced concrete code was published, reflecting the consolidation of a new culture that would be used effectively by the new authoritarian regime of the Estado Novo.

The following text, Chapter1.2, by Edwin Trout, reviews successive steps in Britain's dissemination of Joseph Aspdin's 1824 Portland cement patent and the efforts made to catch up with the reinforced concrete that had had its first commercial success in France and was the subject of theoretical studies and codification in Germany. It describes the institutional constraints initially faced by the first patented systems and licensed contractors. For example, Louis Gustave Mouchel, Hennebique's patent agent, struggled to be accepted by official building regulations, while other actors sought to achieve freedom of design. The study follows this whole process up until the full exploitation and promotion of reinforced concrete was permitted by different regulations, influential texts and the publication of the 1934 UK Code of Practice.

Gilbert Richaud dedicates Chapter 1.3 to France. He begins by underlining the importance of François Cointereaux's studies at the end of the 18th century in revisiting the ancient *structura caementicia* and looking to the creation of a new constructive system of concrete moulding by optimizing the millenary process of *pisé*. This new system was made possible by the development and theorization of high-strength mortars by researchers such as Louis-Joseph Vicat. The author then describes the genesis and great international dissemination of the works carried out in *béton aggloméré* by François Coignet, as well as the large-scale uses of his system of new monolithic masonries. The text goes on to discuss the early works of Gaspard André and Tony Garnier to explain how their pioneering works made it possible to theorize on the use of plain concrete in the construction of walls to create an aesthetic made up of simple volumes with rectilinear lines and reinforced concrete for the construction of floors and roofs.

The following text, Chapter 1.4, by Mario Rinke, looks at the study of the dynamics that were established in Germany and Switzerland for the creation not only of the first guidelines and codes on reinforced concrete in 1904 and 1909 respectively but also of the first calculation methods for reinforced concrete structures. These dynamics involved contractors, industrialists, engineers and architects, institutions and academics confronted with the collapse of some structures and the determination of the authorities to control the whole construction process. Influenced by the testing of the resistance of materials promoted by national laboratories, Swiss and German attitudes differed. In Germany, designs based on proposed calculation methods had to be approved by the authorities. In contrast, the emphasis in Switzerland was on sound knowledge of the building practice and individual responsibility. Alongside the creation of the first legislation, Rinke analyses in detail the knowledge transfer necessary for the emergence in Germany of the first calculation theories by Wilhelm Ritter, Mathias Koenen and Emil Moersch, and their relationship with construction companies such as Wayss & Freytag and cement industry associations. In the case of Switzerland, the author discusses the importance of Robert Maillart and his beamless slabs, and of empiricism in the creation of new calculation theories.

From construction and calculation methods codification in Germany and Switzerland, we move on to the study of the construction history role of cement and reinforced concrete patents registered in Spain between 1884 and 1906 in Chapter 1.5 by Francisco Domouso de Alba. After describing the importance of pioneers like José Eugenio Ribera, Manuel Busto or Juan Manuel de Zafra, Domouso shows how foreign and Spanish patents were used to cover the costs of a material which was supported by little theoretical evidence and how these also provided a means of marketing the material. The text provides an in-depth analysis of the different applications of patent registration in Spain: the creation of specialized new building companies, the productions of new derivative products, the introduction of new methods for prefabrication and industrialization and improved knowledge of the structural behaviour of reinforced concrete.

From Spain, the narrative moves on to Belgium with a text by Bernard Espion, Chapter 1.6, which reviews the contribution of four fundamental figures in the history of construction of particular importance to the dissemination of reinforced concrete in Europe. The first is the Frenchman François Hennebique, who started to establish his great design office in Belgium in the 1890s. Next is the Belgian engineer Paul Christophe, who in 1902 wrote the first book on the different systems of reinforced concrete – a milestone for the definition of the calculation methods used all over the world during a great part of the 20th century. The author then discusses the Franki de Liège company, which made a vital contribution to foundation techniques in reinforced concrete. Finally, the collaboration between Gustave Magnel of Ghent University and the Brussels-based Blaton-Aubert company in the pioneering development of prestressed concrete is analysed.

To conclude our journey through the national dynamics of the introduction of reinforced concrete in Europe, in Chapter 1.7, Tullia Iori examines the case of Italy in four well-defined periods: 1850–1900, 1900–1915, 1915–1935 and 1935–1943. The first period is characterized by the importance of registering national patents on the basis of the results of international patent trials, leading to the creation of new Italian companies that started to offer variations of tried-and-tested foreign systems. The second period discusses the 1908 earthquake in Messina and

Reggio Calabria and the importance of the structural calculations of the Risorgimento bridge in Rome in 1911 in affirming the anti-seismic capabilities of the new building system. After 1915, reinforced concrete was no longer the exclusive domain of patents and small firms, and as of 1929 it was protected by new corporative Fascist legislation. Reinforced concrete began to define a new architectural language. Supply problems due to the First World War improved research into the limits of the new building system.

The second part of the book opens with a case study of the first great British contractors engaged in the new iron and steel constructions designed to connect many regions of the globe by means of railroads, contractors that to a certain extent provided a model for companies from other countries with colonial possessions. Chapter 2.1 by Mike Chrimes studies the mechanisms of emergence of the first well-capitalized national contractors in the UK and Ireland. During the period between 1800 and 1914, these companies not only closely followed the technological transformations in the construction field, but also quickly spread them globally, first through the first canal constructions and then with the construction of the railroads. Examples include the company Waring Brothers, which specialized in railway structures, and Thomas Brassey, who expanded his activity to the manufacture of construction materials and the construction of tramways, sanitation, gas and electricity supplies.

Written by Bernard Espion, Rika Devos and Michel Provost, Chapter 2.2 is dedicated to Blaton, the influential Belgian construction company, from its foundation in 1865 to 1954. Having started out in the trade in building materials – in particular artificial cement – the company would begin executing reinforced concrete constructions in 1897. From 1927 onwards, the third generation of managers diversified the company's activities with the successive creation of several companies specializing in Vibro piles, prestressed structures and real estate operations, leading to its expansion into France and the former Belgian Congo.

Chapter 2.3, by Simonetta Ciranna, explores the activity of the German-born engineer and contractor Rodolfo Stoelcker and his construction company founded in Italy in 1913, from that year up until the post-war period. Since his early work in Germany for Wayss & Freytag, followed by Ferrobeton in Italy, Stoelcker's specialization in reinforced concrete had been a constant. The construction works executed by Stoelcker in collaboration with some of the greatest Italian architects of the Fascist period display the use of the most up-to-date methods of the new construction culture. The study serves to revisit the role of Italian contractors in depth during a controversial period that marked Europe in the 20th century.

Belgium comes into focus once again in Chapter 2.4, by Inge Bertels and Jelle Angillis. The chapter opens with the city of Antwerp in the 19th and 20th centuries to tell the construction history in terms of the activity of construction companies and their relation to steel and reinforced concrete. The system of public tendering and its influence on the creation of new construction companies, the development of their professional status, the first attempts to form modern trade associations and their relationship with the institutions of public administration are studied in the first of these centuries. Then, this relationship among politics, economics, technology and public works is analysed in more detail for the period 1945–1985, using the company Frans Verachtert NV as a case study.

This set of case studies is particularly illustrative of the vital role of public works companies in the implementation and development of construction cultures in contemporary times. Ending in Portugal, the country of departure on this long tour in the history of construction in Europe, Chapter 2.5, by João Mascarenhas-Mateus, Manuel Marques Caiado and Ivo Veiga, examines the activity of 13 public works contractors during the Estado Novo regime (1933–1974). The chapter contributes an analysis of the relationships of each company with firm founders, engineers and architects, other contractors, materials producers and vendors as well as public institutions. The structural solutions, machines, equipment and materials used in different infrastructures are described and used to identify different technological periods depending on infrastructure types.

Many different readings can be made of this book. As with the history of the implantation of concrete construction culture, the story of its contractors can also be taken as a starting point to examine the history of construction in the 19th and 20th centuries. All European countries directly and indirectly mentioned in the following pages have contributed in their own way to shaping our present building culture. In the period from the Enlightenment to the aftermath of the Second World War, there was a shift in the way Europeans build, during a period of two centuries when a strong belief in scientific and economic progress coincided with neoclassical ideals that took antiquity as a model, the construction of modern nations and the great catastrophes of the two world wars. This process and the attendant radical changes in the construction sector were made possible by an effective transfer of theory and applied knowledge among not only the European countries studied here but also others, including Russia and the Soviet Union, as well as between Europe and the USA. Amid the struggle for the more favourable geostrategic results, these transformations expanded to other regions of the globe under European colonial administration.

The editor wishes to express their immense gratitude to the authors and co-authors for all their efforts, patience and support. This work would not exist but for the time, knowledge and generosity they invested in a special word of recognition to Manuel Marques Caiado. Sincere thanks also go out to Kate Major Patience for proofreading every chapter, and to the team at Taylor & Francis (the Netherlands), in particular Janjapp Blom, Kaustav Ghosh, Jahnavi Vaid and Balaji Karuppanan.

We wish you a fruitful read of this collection of essays written within the framework of construction history in which we endeavour to contribute to a solid understanding of contemporary cultures of building.

Part 1

From Lime and Masonry to Portland Cement and Reinforced Concrete

A Paradigm Shift in Construction Cultures

Chapter 1.1

The Reception of Cement and Reinforced Concrete in Portugal Before 1935

João Mascarenhas-Mateus

Introduction

The aim of this book is to offer a journey through history and different European experiences of the adoption of the construction culture of cement and reinforced concrete in the 19th and 20th centuries. The period radically transformed and shaped our contemporary culture, with a paradigm shift in the ways each country organized itself in its daily building activity linked to the introduction and consolidation of Portland cement and reinforced concrete in the culture of each society. After millennia of construction cultures based on stone and brick masonry with air lime mortars, rammed earth and carpentry, and in the new era of steel constructions, this new material and building process would radically change building in Europe and the world, conditioning the way in which construction takes place today. The shift implied a new dynamic of dissemination, experimentation, construction of a consensual reputation and adaptation of the entrepreneurial and productive systems in each European country.

With this first chapter, we begin this journey in time from a geographical location situated at one end of Europe, Portugal, a country with its own historical path, part of a particular geopolitical environment and with specific natural resources, industrial contingency and construction traditions.

Various Stages for a Major Change

As in the paradigm shifts theorized by Thomas Kuhn (1970) and others in relation to scientific revolutions – as well as by Wallace (1972) in a more focused way in terms of paradigmatic processes in culture change or even by Arditi (1994: 604), who defines cultural paradigms as simultaneously epistemological and ontological – the transformation of building culture in Europe (and in Portugal, in particular) of the 19th and 20th centuries clearly has stages (Mascarenhas-Mateus & Castro 2018). Thus, while avoiding a deep dive into the fields of anthropology and cultural sciences, the present analysis will aim to demonstrate that the transformation that occurred in Portugal had the following stages:

Initial phase(s) – The established paradigm of the constructive culture of masonry and carpentry was called into question. This period coincided both with the new constructive needs of industrialization and with innovations in research on the chemistry of hydraulic binders, the optimization of steelmaking and steel-rolling processes, structural calculations, materials' strength and the constant improvement of steam engines, transportation, communications, and knowledge dissemination. These are stages in the shaping of the new paradigm in which innovations solved simple problems, while academics and industrialists directly linked to the new paradigm continually generated new ideas and opened up new lines of research.

DOI: 10.1201/9781003368656-3

Intermediate phase(s) – Partly overlapping with the previous phases, this covers the periods in which alternatives to the construction systems of the established paradigm were tested and experimented with in a period that Kuhn called pre-scientific. In this period, hydraulic limes and Portland cement emerged as the ideal substitute for air limes; and steel-laminated profiles were proposed as alternatives to timber elements in carpentry and were used with masonry to obtain lighter and more efficient load-bearing mixed floor systems. The hydraulicity of limes and cements was subject to scientific study, theories were established for the behaviour of elastic materials, new kiln systems for cement production were patented and so on. A good reputation was built up for these new materials and processes by producing prototype constructions and advertising for commercial purposes. The quest for earth-framed constructions optimization and their association with Portland cement and rolled steel led to the first reinforced concrete patents. The first buildings were constructed with the new system, and improvements to the system were learned from the behaviour anomalies (see collapse of all the structure) of some of those prototypes. During the intermediate phase or phases, the new paradigm started to be embraced not only by academics who began to want to codify it but also by economic, political and military organizations.

Consolidation phase(s) – Once a consensus on the new system had been obtained from the academic, industrial and commercial spheres of society, reinforced concrete was rationalized and standardized in each country's legislation as regards its modelling or calculation, the production and commercialization of the materials which compose it, its application on site with maximum economies of time and materials, the training of technicians and workers and knowledge transfer. This period, referred to by Kuhn as "scientific", saw the definitive consolidation of the introduction of the new paradigm and its institutional recognition. The result was the replacement of the old paradigm by the new one. Reinforced concrete became the constructive system consensually and rationally accepted as the best constructive system, relegating masonry and carpentry to a secondary plane. This dynamic implied "functional consequences", as defined by Wallace, such as the change in the nature and hierarchy of the different classes of construction workers, the codification of the responsibilities of architects and engineers and so on.

These three stages probably occurred in all European countries during the 19th century and until the period between the two world wars, at a faster or slower pace depending on the state of scientific development and economic, political and cultural characteristics of each nation. Just like other countries, Portugal went through all these stages, in some aspects keeping up with the more advanced countries and in others taking more time to adapt.

The industrialization of territories and nations demanded – with the minimum of time and money – the construction of:

- new large industrial buildings with large open spaces for the installation of mass assembly lines for products;
- large, multi-storey, highly fire-resistant buildings capable of holding large volumes of goods, machinery and people;
- river and maritime works such as harbours, jetties, quays and harbour docks for the movement of raw materials and manufactured products;
- railway and highway bridges for the terrestrial movement of people and commercial products;
- healthy buildings for the rural and working populations linked to the new factories.

At the same time, from the beginning of the 19th century, cast iron and rolled steel profiles began to be a common building material answering to those demands, for large-span building roofs, road and railway bridges, and for the transformation of existing masonry buildings to increase the spans of façades and the free space inside. For this reason, the construction systems of masonry and carpentry were optimized and pushed to their material and strength limits. See, for example, the various memoirs on cut-stone masonry reinforced with iron elements such as those proposed by Jacques-Germain Soufflot (1713–1780) in the case of the Church of Sainte-Geneviève in Paris, revisited by Rondelet in his *Mémoire historique sur le dôme du Panthéon français* (1797) or the seminal studies on the optimization of rammed earth by François Cointereaux (1740–1830).

The new building culture of cement and concrete would initially take shape in a historical period known as the "steam and steel" age, during which steam engines, iron and steel seemed capable of overcoming almost any technical difficulty and achieving grandiose constructions the likes of which had never been seen before.

Early Phases: Hydraulic Piers, Artificial Cement, Iron and Steel (1835–1886)

As far as masonry binders are concerned, if compared to natural hydraulic limes and the first artificial cements, air lime presented limitations for building ever-increasing volumes of resistant foundations in fluvial and maritime areas within a short period of time. Air lime has long hardening times, requires admixtures to acquire a hydraulic behaviour and corrodes the iron in reinforced masonry. Meanwhile, masonry vaults were no longer the most suitable device for covering spans that were necessarily increasing. And carpentry roofs were easily consumed by fire. For those reasons, a new era began when new materials and systems capable of responding to all these new needs were being dreamed up and tried out.

In this context of new construction demands, Portugal followed the discussions on and improvements to construction that were being developed in the rest of Europe and the USA – especially through the specialist articles published systematically in the bulletin of the recently created Ministry of Public Works, Commerce and Industry (1852), whose first issue dates back to July 1853. The same would occur in a fragmentary way in the scientific journals created by industrial societies and associations, such as the *Annaes da Sociedade Promotora da Indústria Nacional*, published in 1822, or the *Jornal da Associação Industrial Portuense* as of 1852. This dissemination extended to the general public in a range of diverse journals, from *O Industrial Civilizador* (1835–1836), *O Recreio* (1835–1842), *O Panorama* (1837–1868) and the *Gazeta dos Caminhos de Ferro* started in 1848 to the *Archivo Pittoresco* (1857–1868) or the illustrated magazine *O Occidente*, founded in 1877.

At a time of dissemination in print of European advances, an article published in 1835 in the *Annaes da Sociedade Promotora da Indústria Nacional* (Anonymous 1835a)[1] gives an account of the studies being produced in chemistry and mineralogy linked to the composition and manufacture of hydraulic limes and cements, in particular those of Louis-Joseph Vicat (1786–1861), Pierre Berthier (1798–1848), Johann Friedrich John (1782–1847), Antoine Raucourt (1789–1841) and of General Treussart of the French Corps of Military Engineers. The text also mentions the Roman cement of James Parker, the "ciment romain de Pouilly-en-Auxois" of Jean-Auguste Lacordaire (1789–1860), the pozzolan of Vivarais and the works on slow-setting and quick-setting cements by Alexandre Berthault-Ducreux (1790–1879). Apart from the very up-to-date information on different authors and theories, the following excerpt of the article is particularly prescient, revealing how research into new hydraulic binders was of great interest to the industrial societies of the time:

then it may be expected that in most of the countries where the calcareous rock is found, one can also find the different varieties of cements [. . .] Geology, whose study further develops day by day, takes charge of classifying the varieties of the calcareous rocks and determining their subordination within this classification: with its help [. . .] the layers within the calcareous forms able to reproduce lime and the cements of the different varieties will be found everywhere [. . .] A knowledge of hydraulic lime and cements offers us the means of making constructions that last at least as long as those of the ancients; in many cases, it will be possible to dispense with the costly use of thick materials and of masonry stone and henceforth the construction with gravel and mortar, of which the Romans have left such beautiful and durable models, may again be used [. . .] so that all dwellings may be healthy [. . .] so that its use will in many circumstances offer us many objects of taste and utility without great expense, facilitating the construction of terraces, platform roofs, cisterns, basins and aqueducts, so that finally its discovery will be one of the most precious, most important and most useful of the century; yet, it is unknown to many countries, and is in great need of being propagated and popularized.

(Anonymous 1835b: 58–60)

Additionally, the Portuguese translator of the article, serving as a mediator, applied his creative reason to the original text, giving an aesthetic and functional interpretation of the capacity of these new materials to cover the ruins of the churches of San Francisco and Carmo (in Lisbon) destroyed by the 1755 earthquake, with “terraces and belvederes that would offer visitors to the capital a panoramic view of incomparable delight” (Anonymous 1835b: 60).

This first dissemination period is accompanied by the importation from the UK and France of these new hydraulic binders, in particular the so-called “Roman” cements as of the 1840s.[2] Around the same time, pozzolana began to be imported from Italy,[3] first for the execution of the Azambuja Canal by the Company of Canaes d’Azambuja, possibly under the influence of the Milanese Giulio Sarti (1792–1866), director of the works since 1845 (Brandão & Malaspina 2022: 177). A little later, the pozzolana called *massapez* extracted on São Miguel Island in the Azores was studied according to Vicat’s methods, along with the strength of mortars and concretes used on the construction of the walls of the Ponta Delgada customs quays in 1855 (Lopes 1856). From the 1860s, this pozzolana was exported to the mainland (Machado 1867).[4] As regards Portland cement, one of the first mentions of it is made in the specifications of the preliminary project of 1864 for rejointing the stonework pillars of a metal road bridge over the Douro River, on the road between São Pedro do Sul and Vila Real (Maia 1866).

Parallel to the new circulation of hydraulic binders, the technical disclosure of the construction system in plain concrete with hydraulic binders that would have the greatest impact in Portugal was that of François Coignet (1814–1888) right after its presentation at the Universal Exhibition of Paris in 1855. The following year, Carlos Augusto Pinto Ferreira, delegate of the “Lisbon Artists” to the exhibition, published a report “offered to the Centre for the Promotion of Improvements to Working Classes”, in which he notes:

Coignet’s artificial stone in moulds of movable coffers: In certain areas of our country this construction would be of great advantage, and perhaps would not cost more than constructions made with rammed earth, which have neither the appearance nor the duration of this composition.

(Ferreira 1856: 34–48)

In 1857, and following an article published in the journal *Correio da Indústria* in that same year, Coignet's discoveries capable of replacing masonry and carpentry were presented in the Bulletin of the Ministério das Obras Públicas, Comércio e Indústria (Ministry of Public Works, Commerce and Industry) and its application in Portugal, in the following terms:

> Mr Coignet has discovered a method for the composition of mortars, which makes them so solid that they can be laid without the need for carpentry works. [. . .] Moreover, with equal hardness and strength, the mortar is better than stonework since it can become monolithic, featuring no joints [. . .] Mr Coignet cites the following applications for his invention: Cellars and completely dry workshops; economical and incombustible floors and roofs; all hydraulic and road works such as bridges, viaducts, aqueducts, cisterns, reservoirs and silos suitable for the conservation of solid or liquid products and especially paving stones [. . .] In a country like Portugal, where stone is cheap, Mr Coignet's invention does not have the same importance as in countries where it is worth double, triple and more; but even so it deserves to be studied and offers applications that do not seem to us to be negligible.
>
> (Anonymous 1857: 597–599)

In addition to scientific and commercial dissemination, a new construction culture requires for its implementation the direct interest of the State, not only to establish customs duties for imported materials but also for their study and dissemination. Just as for the 1856 study on pozzolanas from the Azores by Captain João Luís Lopes, Director of Public Works in Ponta Delgada, a study on the manufacture of plain concrete was also commissioned in 1861 to serve as a guide for its practical application by the engineer Silvério A. Pereira da Silva, Director of Public Works in Aveiro. In his report, Pereira da Silva describes the dosages and prices of concrete used in the construction of 152 linear metres of quay walls and 200 metres of jetties in the Port of Aveiro with plain concrete made of natural hydraulic lime and pozzolana from the Azores. The Sobral bridge in Aveiro, possibly the first plain concrete bridge built in Portugal, is also described. The arch bridge was built in 1860 with natural hydraulic lime concrete and had 9.0 m span, 1.5 m rise, 0.9 m thickness at the key, 1.0 m thickness at the abutments and 6.1 m average width. The 44 cubic metres of concrete were transported by a team of women, probably on head baskets, and the concreting process was completed in 24 hours. This experimental achievement is put by the author on an equal footing with the best practice of the time in France. At the same time, it reveals how Coignet's model clearly contributed to cost and time savings compared to the stone masonry then common.

> The principle of Mr Coignet's process consists of thoroughly beating in moulds or boxes similar to those used in the construction of walls of tapia (pisé) a very thin mortar, improperly classified as beton [. . .] There are in Paris different works built using this system: a large workshop, a three-storey house built entirely of beton, a curtain wall 6 metres high, and other works, including lowered arches 6 metres wide with 0.1 m of deflection, etc.
>
> (Silva 1861: 3, 168)

As recommended in the 1835 article published in the Annaes, in Portugal, geology also became an instrument for surveying the potential of the areas of the country rich in limestone and marl formations suitable for the establishment of the future cement industry. With the first geological map of the country (scale 1:500,000) finished in 1864, the engineer José Neves Cabral (1827–1903) highlighted the potential of the argillaceous limestones in the area between Nazaré and the Liz River, and José Oliveira e Souza (1839–?) compared the cement made of Setúbal limestone with English Portland cement (Sousa 1867). The areas indicated in blue on the map (Figure 1.1.1) corresponding to the Jurassic (Lusitanian) age, rich in marl and limestone, were from then on clearly known. The natural deposits situated north of the Tagus River became the site of the natural hydraulic lime, natural cement and finally Portland cement factories that started to be opened. Contemporary to the geological survey of the country, in 1866, a ministerial commission led by Francisco da Ponte e Horta (c. 1790–) was created to undertake all types of essays of the materials strength used in construction, including cements and hydraulic conglomerates in a more systematic way.[5]

This rush to produce hydraulic binders was motivated by the first systematic planning of public works (railways, ports and roads) aimed at transforming the country to suit the various nascent industries, under the management of the Ministry of Public Works, Commerce and Industry. A first Portuguese concession to produce artificial cement (Afonso 1857) never came to fruition. The effective production of "natural cement" started in 1866 under the brand Rasca, manufactured in Alcântara, Lisbon, by Francisco Afonso Sanches de Gusman y Nogueira, the main partner of the company of hydraulic lime and natural cement with marly limestones brought by boat from the area of Rasca, Setúbal (Oliveira 1999: 56–59). With the constitution of the Companhia Mineira e Industrial do Cabo Mondego in November 1873,[6] a regular production of hydraulic lime began together with natural cement under the brand Pharol (Anonymous 1897: 3) that would begin to rival the French Theil lime (Anonymous 1928).

Despite the increase in national production, imports of hydraulic lime and Portland cement, mainly from the UK and France, also increased due to the growing demand for materials in the

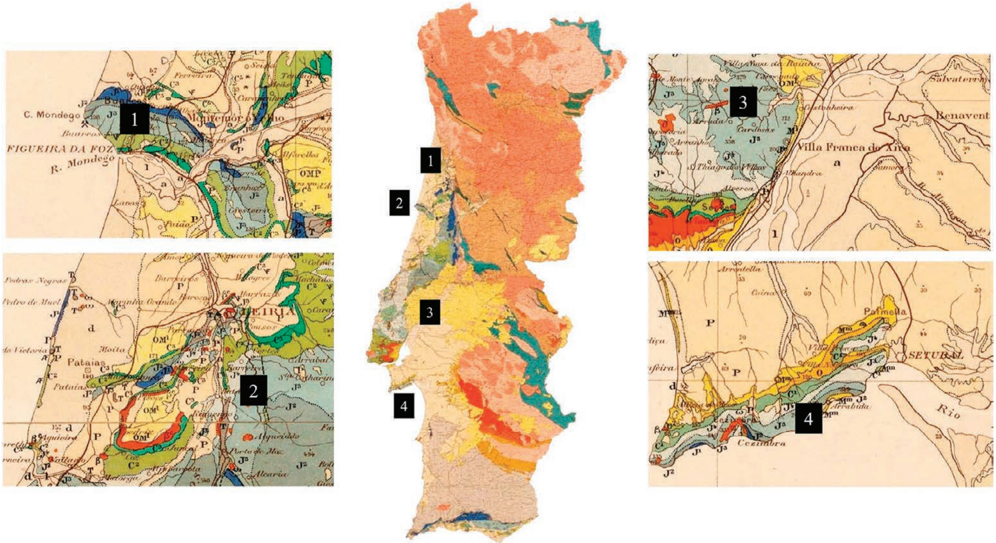

Figure 1.1.1 Areas rich in marl and limestone marked in blue in "Carta Geológica de Portugal 1:500.000" by Joaquim Filipe Nery Delgado (1835–1908) and Paul Choffat (1849–1919) published in 1899 by Direcção dos Trabalhos Geológicos, based on the 1876 survey done by Delgado and Carlos Ribeiro (1813–1882).

Source: Europeana and Biblioteca do Exército.

first period for the foundations of the numerous metallic bridges required by the national railway network initiated in 1852. In the first stretch between Lisbon and Santarém of the East Line, metal bridges such as the Sacavém, Asseca, Praia do Ribatejo or Caia bridges, built between 1853 and 1863, had foundations built with caissons sunk by compressed air under the management of English and Spanish contractors. Then came the Northern, Minho, Douro, Beira Alta, Beira Baixa and South and Southeast lines, among others, where the metal bridges and some tunnels were built by French companies (Gustave Eiffel, Duparchy, Bartissol, Fives-Lille, Cail & Cie), Belgian (Braine-le-Comte) and even German ones (Johann Caspar Harkort) – besides the main contractor, the Real Companhia dos Caminhos de Ferro Portugueses, managed by the Spaniard D. José de Salamanca y Mayol (1811–1883). Most of the decks built by these companies were initially imported and assembled *in situ*. In a few cases, these decks were supported by metal piers for major heights but most often by masonry pillars or cast-iron pillars filled with plain hydraulic concrete (Figure 1.1.2). The execution of masonry arch bridges was normally assigned to local Portuguese contractors.

Portland cement would also be used on a large scale in the construction of harbour quays and jetties. From early experiences involving figures such as Léopold-Victor Poirel (1804–1881) in the 1830s for the construction of the Port of Algiers (Poirel 1841), the use of artificial concrete blocks became a common technique (Figure 1.1.3). In Portugal, an 1865 project by Manuel Afonso de Espregueira (1835–1917) was one of the first to propose the use of Portland cement concrete blocks using the Poirel system for the construction of the Port of Leixões (Blanc 1874:

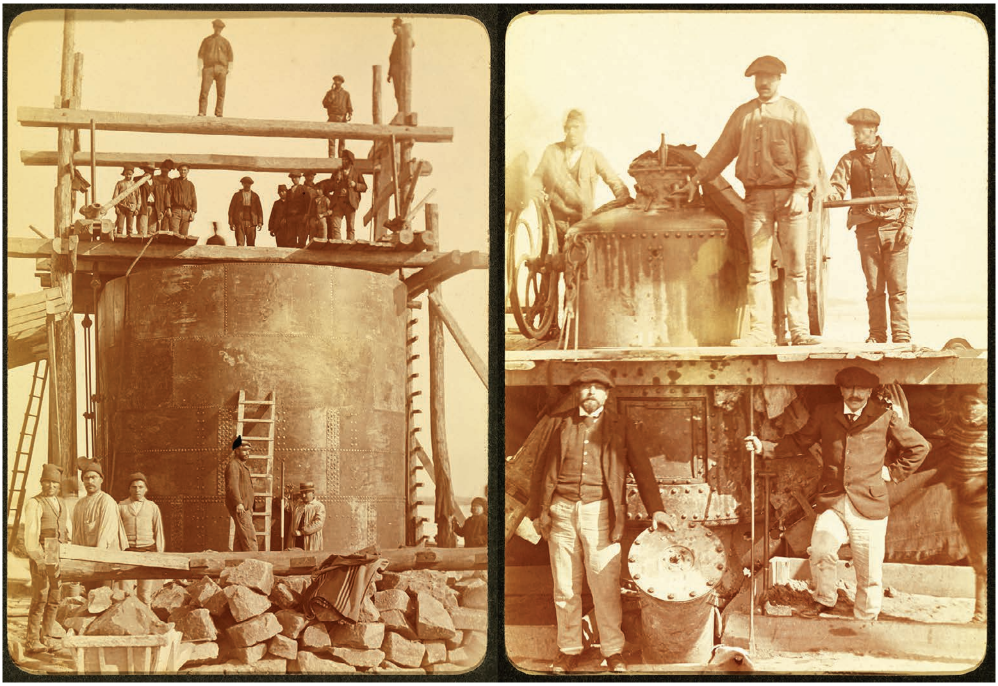

Figure 1.1.2 Left: Steel pneumatic (compressed-air) caisson for the foundation of one of the Rainha D. Amélia bridge piers (1904) to be filled with plain concrete. Right: Air lock used by staff to enter and exit the caisson.

Source: Espólio Touzet, CDFEDP – Centro de Documentação da Fundação EDP, Lisbon.

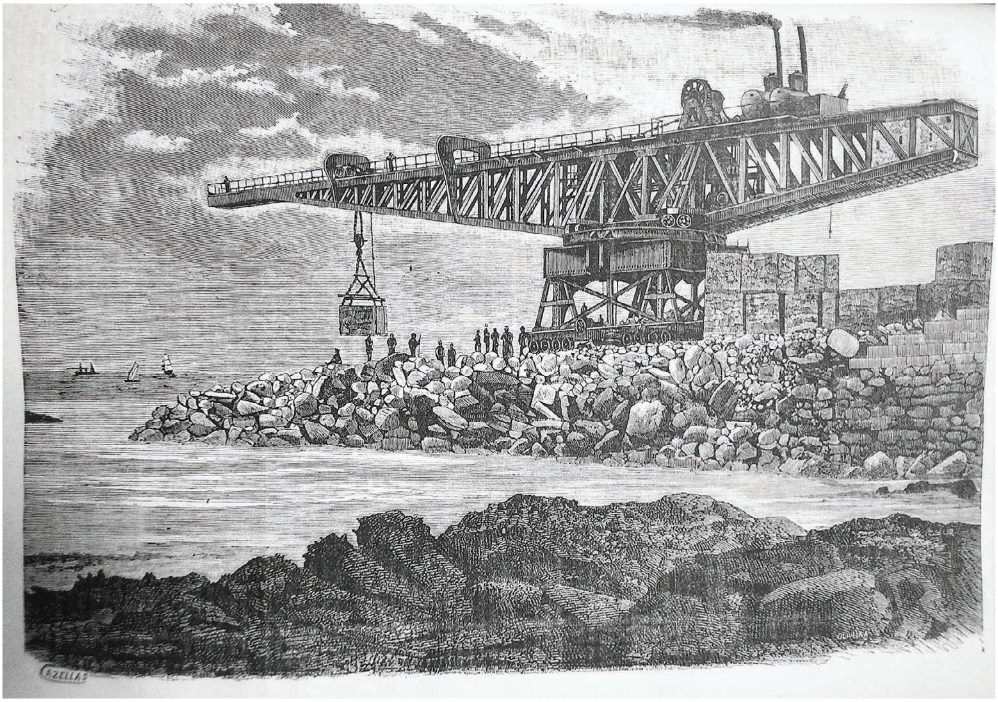

Figure 1.1.3 Concrete blocks in jetty construction for Leixões harbour (1884–1892), made with British and German Portland cement from the French contractor Dauderni & Duparchy (later Duparchy & Bartissol). One of the two Titan cranes made by the French Compagnie de Fives-Lille is visible.

Source*: Engenharia* e *Architectura* 1891, (I) 41: 321, Ordem dos Arquitetos Library, Lisbon.

244–245). For the construction of these blocks, Candelot cement would be imported for the Port of Ponta Delgada (started in 1861). German cement from the Stern brand and British cement from the Gillingham brand were used for the Port of Leixões, started in 1884 (Figure 1.1.3), and French cement produced by the Société des Ciments Français de Boulogne-sur-Mer and Lafarge was used for the Port of Lisbon (1888) (Sequeira 1920: 145–149). Prefabricated concrete blocks in Portland cement were also used in the African colonies, as in the Port of Lourenço Marques in Mozambique in 1897 (Silva 1901), and were proposed for the Port of São Vicente Island in Cape Verde in 1898 (Loureiro 1898: 374–375).

Besides its use for harbour quays, plain concrete with Portland cement also became common in projects to build reservoirs, foundations of factory buildings, canals and water and sewage pipes. For instance, in 1860, during the construction of the foundations for the building of the new Oporto Customs House, the following announcement was made:

> We are told that two large barrels for making mortar have been ordered, which are expected to establish a large mortar and concrete workshop, in which the main work is to be done by a locomotive machine with the strength of six horses, which arrived some time ago, in the workshops of the machinist F. Calla. This steam workshop is intended almost exclusively for the foundations of the building.
>
> (*Diário do Governo*, 1 June 1860, No. 125: 582)

This process took longer in the colonies, and only in 1890 do we find a record of the application of Portland cement in the covering of the pipes of the Moçâmedes–Bihé railway in Angola (Machado 1890: 290).

At the same time, cast iron and rolled steel profiles began to be the materials of choice for above-ground construction: industrial buildings, road and railway bridges, the creation of openings in façades and inside existing masonry buildings. Traditionally, iron imported in ingots was forged and transformed into "arame, verguinhas, varões, vergalhões, barras chatas" ("wire, wires, rods, rebar and flat bars").[7] In 1841, the State Gazette (*Diário do Governo*) no. 190 of 14 August started to define import duties for cast iron in ingots and bars and for crude steel. After the import rights for rolled iron rails, it was the turn of the prices for the transport by railway of raw, forged, cast and rolled iron, published in State Gazette no. 305 of 28 December 1858. This iron import market began to be controlled by a small number of companies founded by foreigners settled in Portugal associated with Portuguese entrepreneurs such as Mahony & Amaral, Orey Antunes & Cia, A. Black & Cia, Sommer & Cia and H. Vaultier & C[a]. Only from 1870 onwards did Portuguese companies emerge that were capable of truly producing and assembling bridges and large industrial buildings in imported rolled steel profiles, such as Empreza Industrial Portugueza[8] or Cardoso, D'Argent & Cia.

Intermediate Stages: A Cement Industry and the Advent of Reinforced Concrete – Experimentation and Standardization

A second period of implementation of the new cement and concrete culture can be defined from the moment when Portugal started to test and assess the various compositions, strengths and behaviours of the new construction materials from the chemical, mineralogical, and physical point of view in a regular and institutionalized way. The advent of reinforced concrete took place in this context.

This relative scientific and applied autonomy was possible from 1886 onwards with the creation of the Section for Studies on Strength of Materials of the Department of Mechanics of Materials of the Directorate of Port Works of Lisbon.[9] The works on the new port were then being executed by the engineer Hildevert Hersent (1827–1903) with the sinking of caissons and the use of compressed air and prefabricated concrete vaulted slabs (Hersent 1888). The first director of the laboratory was José da Paixão Castanheira das Neves (1849–1922), who authored a series of studies evaluating the situation of Portuguese building materials (Neves 1900). Furthermore, he was the figure who established the first guidelines for a Portuguese Portland cement industry under the most advanced theories of the time, publishing many of his studies in the *Revista de Obras Públicas e Minas*. In 1891, he produced a study on Portuguese natural cements, classifying them into Roman cements (Rasca and Cabo Mondego) and quick cements (Pataias, Maceira and São Pedro de Moel). The following year, he compared the different hydraulic cements available on the market. In 1892 and 1893, he wrote about the mechanics of materials, and in 1894 he analysed a total of 63 samples of the most common brands of British, French, Belgian and German cements (natural, Portland and slag) sold in Portugal, some samples from Spain and one sample from the USA. In 1907, he published a study on Portuguese pozzolana from the Azores.

In response to the ever-growing demand for cement, the factories at Cabo Mondego and Rasca were joined in 1891 by the Fábrica de Cimentos da Maceira (Figure 1.1.4) belonging to João Henrique Teixeira Guedes (1852–1924), which boasted of a continuous Dietzsch shaft kiln. In the colonies, the Green Island Cement Company Factory was established in Macao in 1886 (Silva 2015: 283).

Figure 1.1.4 Cover and back cover of a commercial publication promoting the Fábrica de Cimentos da Maceira's products (Guedes 1900).

Source*:* The author's private collection.

Finally, in 1894, the Tejo Cement Factory was opened in Alhandra as the first Portland cement factory in the country. The plant started its production with a Hoffmann kiln which was replaced in 1903 by four Candlot-Lavocat kilns. In 1906, a second Portland cement factory was opened in Rasca, Setúbal, with Belgian capital and three vertical Candlot-Perpignani kilns. This was followed, in 1923 and in the same geological region of Maceira, by the construction of the country's largest cement factory, Maceira-Liz, owned by the Empresa de Cimentos de Leiria, with two rotary kilns supplied by G. Polysius. In the colonies, the Matola factory was set up in Lourenço Marques, Mozambique, in 1918.

At this time, the Portland cement industry also began to supply new by-product industries, including hydraulic tiles and fibre cement sheets and pipes. The process of "compressed cement" tiles is described in detail (Silva 1896: 140–142) by the first Portuguese producer, Francisco Liberato Telles de Castro da Silva (1843–1902). The company Goarmon & Cia. became a national landmark for the production and sale of hydraulic mosaics. Silico-calcareous bricks were produced by the Empreza Cerâmica de Lisboa in 1903 (A Construcção Moderna, 117: 264). From 1908, the magazine *A Architectura Portuguesa* began to publish advertisements for fibre cement (Viterbo & Valente) and cement blocks (Goarmon & Cia.).

At the same time that a national Portland cement production network was being created, the composition and manufacture of concrete were incorporated into engineers' training. The application of the new materials was already being taught to the engineers trained at the Escola do Exército (Army School) in the academic year 1882–1883 (Pedrosa 1882). Technical dissemination diversified with new periodicals such as *Engenharia e Architectura* (1891–1896), *Revista de Engenharia Militar* (1896–1916), *A Construcção* (1893–1898), *Construcção Moderna* (1900–1919), *Revista Técnico-Industrial* (1916–1918) or *A Architectura Portugueza* (1908–1930). Advertising for foreign and national cements was present throughout the general and specialized press with small technical advertising booklets for each of the national brands, accompanied by statements from architects and engineers on their application in different works.

Unlike the introduction of hydraulic binders to the country's construction culture, which had already taken almost 50 years, the introduction of reinforced concrete was a much faster process.[10] The new construction process would be the subject of successive patent registrations, such as those of Remi-Jean-Paul Contancin (1865–1917/28)[11] in 1892 and François Hennebique in 1895.[12] Jacques Monet, the first licensee of the Hennebique system, together with Herculano Galhardo (1868–1944), director of the Alhandra factory, tested a reinforced concrete floor slab and beam on 14 July 1896 (Oliveira 1999: II–107). In 1898, the Caramujo factory was completed, Hennebique's first reinforced concrete grid building in the country. On 26 October 1898, M. S. Reynaud & Cia., the licensee of Paul Cottancin since 1892, tested a reinforced concrete floor slab at the Lisbon Medical School (Menezes 1899) in the presence of Cottancin, who on his visit to Lisbon gave a lecture at the Portuguese Civil Engineers' Association (Figure 1.1.5).

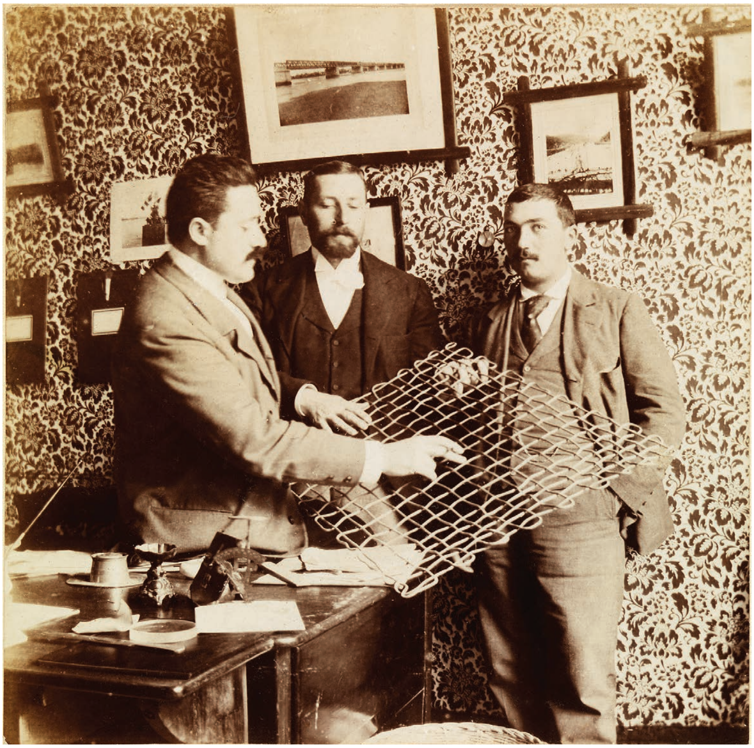

Figure 1.1.5 Paul Cottancin (?) (left) holding a model of his reinforced concrete system at the office of M.S. Reynaud (centre), in Lisbon, *ca*. 1904.

Source*:* Touzet Collection, CDFEDP – Centro de Documentação da Fundação EDP, Lisbon.

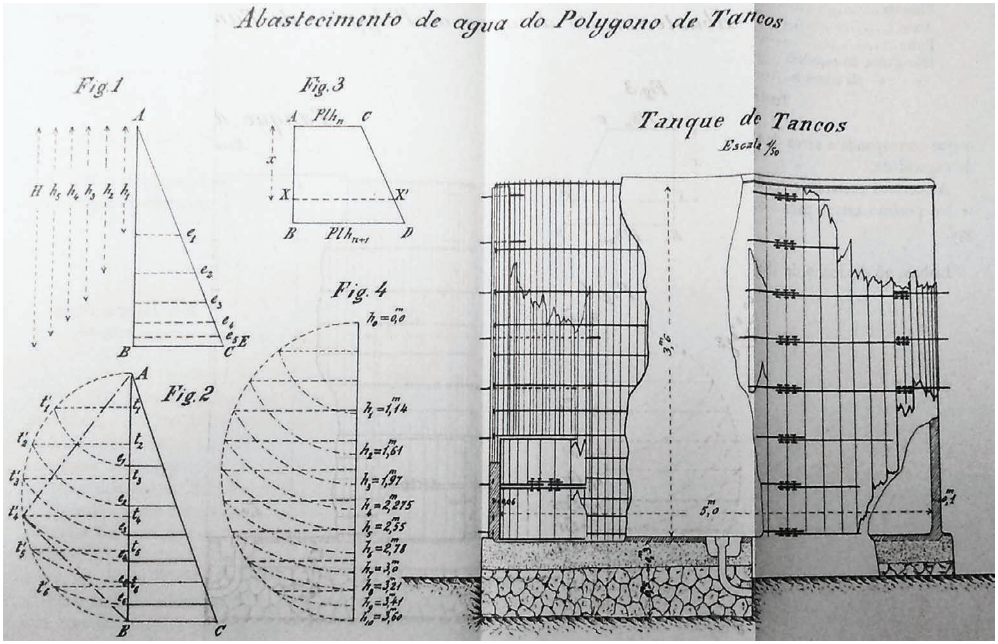

Figure 1.1.6 Plans for the water tank at the Practical School of Engineering in Tancos, 1899.
Source: Peres (1899), Military Academy Library, Lisbon.

In that same year, a project was introduced for the Home for the "Irmãzinhas dos Pobres de Lisboa" in the Pinheiro Manso area, in Oporto, where "all the floor slabs destined for the service of the old boarder men are built with double T-shaped iron beams whose intervals should be filled up by either reinforced cement or brick vaults".[13] The following year, the Pombal water tank for the Practical School of Engineering in Tancos (Figure 1.1.6) was built by military engineer José Joaquim Peres, according to the design by another military engineer, João Severo Cunha, who used Hennebique's formulas for its calculation. The reservoir (interior dimensions: 3.7 m high and 5.0 m in diameter; exterior dimensions: 4.1 m high and 5.2 m in diameter) used a skeleton made with a riveted flat-bar lattice and concreted between wooden formworks (Peres 1899).[14]

In 1901 and 1903, military engineer Augusto Vieira da Silva (1869–1951) used reinforced concrete to build mangers, immersion tanks and washbasins in the headquarters of the Pontinha Sappers Company (Silva 1901, 1903). Reinforced concrete also reached the African colonies and was used, for example, on the Mortuary of the Mozambique Company Hospital, in Beira (Maia 1909) and on a jetty (Figure 1.1.10) begun in 1911 using the Hennebique system by the company L. G. Mouchel & Partners in Lourenço Marques, Mozambique (Veiga 1914). In Angola, pier-bridge projects on Mitchell screw piles were also completed, and there are records showing balconies in reinforced concrete added to buildings in the port of Lobito (*Revista de Engenharia Militar* 1914, 19: 52–80).

However, from 1902 to 1905, Bernardo Joaquim Moreira de Sá (1879–1919) – later the company Moreira de Sá & Malevez, holder of the Hennebique license as of 1905 – was responsible for most of the first reinforced concrete works in Portugal, during the transition from the monarchy to the Republic (1910) and until the Great War of 1914–1918: water tank towers, firefighter training towers, road bridges, silos, domes, beer halls, wine vats, industrial pavilions, spas, terraces, balconies, staircases, and so on, and most of them featured in the monthly magazine *Le Béton Armé* founded in 1898. Examples include the firefighter's training tower (1903) in Porto, the Vale de Meões bridge (1904) in Mirandela with two parabolic arches of 19-m span, the Luiz Bandeira bridge (1907) with two parallel arches of 32-m span, a 19-m high water tower in Lisbon and the Alcáçovas Dam.

But this period was not only characterized by Hennebique's achievements. The magazines *Construcção Moderna* and *A Arquitectura Portuguesa* report on important reinforced concrete works designed by architects such as António Rodrigues da Silva Júnior (1868–1937), the designer of the Hotel Palace do Vidago (1908–1910), built by the Empreza Construtora do Porto (Figure 1.1.7; the new Theatre of São João in Oporto (begun 1911) by architect José Marques da Silva (1869–1947)); the building of the Portugália beer factory in Lisbon (1912–1913) by contractor Fernand Touzet and the Grandes Armazéns Nascimento in Oporto (begun 1916) by architect Marques da Silva. The *Revista de Engenharia Militar* presents the 70-m long (14 spans of 5.0 m each) road bridge over the river Xarrama in Viana do Alentejo with a 12-cm deck on three beams of 0.38 m × 0.20 m supported by piers 0.30 m × 0.20 m built by the engineer Augusto Vieira da Silva between 1915 and 1916 (Silva 1916a). The same engineer was responsible for the Companhia das Águas de Lisboa workshop building (Figure 1.1.8) built with reinforced concrete floor slabs 12 cm thick and a thin roof also in reinforced concrete 6 to 10 cm

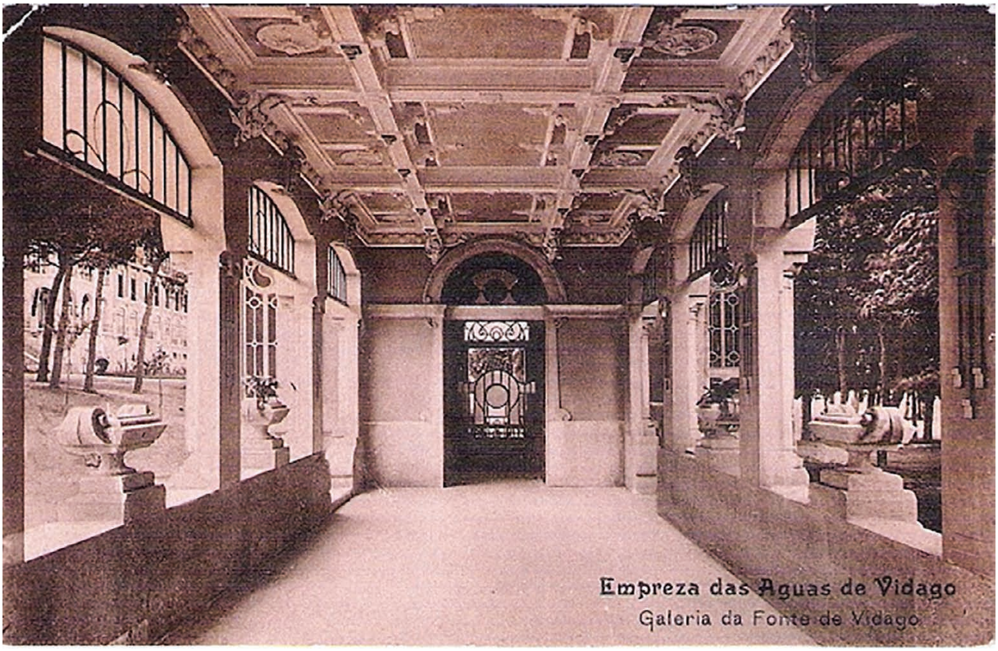

Figure 1.1.7 A reinforced concrete gallery ceiling in the bath house of Hotel Palace do Vidago designed by architect António Rodrigues da Silva Júnior and built by Empreza Construtora do Porto, from 1908 to 1910.

Source: Postcard, author's private collection.

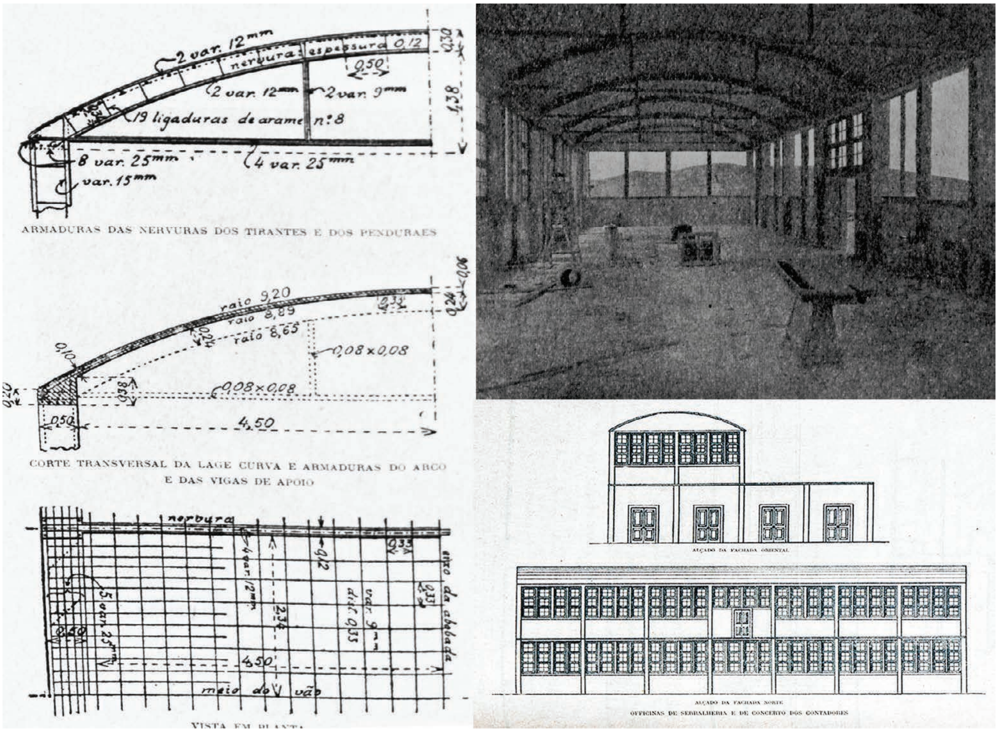

Figure 1.1.8 Companhia das Águas de Lisboa reinforced concrete workshop building covered with a thin roof 6 to 10 cm thick designed by Augusto Vieira da Silva and built in 1916, with reinforcement bars details, plan of the façade and photo of the interior (Silva 1916d: 100, 108).

Source: *Revista de Obras Públicas e Minas*, Arquivo Histórico do Ministério das Obras Públicas, Lisbon.

thick (maximum surface 34.0 × 19.6 m) (Silva 1916d). Other notable engineers in this period were Ferreira Mesquita (1861–1935), Augusto Sequeira and Raul Couvreur (1879–1959). Contractors specialized in the new building system worth mentioning include J. Ducasse, Domingos Mesquita & Cia, Sociedade de Engenharia ERG founded in 1920, A. Construtora, Virgilio Preto, Soares da Costa or the Companhia Nacional de Construções directed by David Xavier Cohen (1850–1913). These builders capable of executing reinforced concrete structures began to be publicized in engineering and architectural magazines alongside the existing contractors specialized in masonry, stone cutting or ornamentation with plaster.

The network of retailers and representatives of the materials necessary to execute reinforced concrete adapted to this context, and they also began to advertise more frequently not only the Portland cement necessary for reinforced concrete[15] but metal products such as *metal deployé* (expanded metal) as well. The first edition of the *Guia dos Chefes de Conservação e Apontadores de Obras Públicas* (*Guide for Conservation Managers and Surveyors of Public Works*) reveals a high availability of iron and steel profiles from the many Portuguese metal suppliers: iron or steel rods with diameters of 2 mm to 20 mm and 5 metres long; wire with diameters of 1–2–3 mm in rolls; and different sections of rectangular bars 5 metres long (Lobo 1915: 253). The Antas Factory in Oporto, created in 1895, produced iron mesh for reinforced concrete and had representatives in Angola, Cape Verde and Mozambique. In fact, the necessary materials (cement, steel bars, sand) were easily available throughout the Portuguese territory.

As regards the dissemination of technical knowledge of the new system, many technical articles on the use of reinforced concrete began to be published in *Revista de Obras Públicas e Minas*, *Engenheria e Architectura* and *Construcção Moderna e Arquitectura Portuguesa*. From 1891, *Engenheria e Architectura* published a series of articles disseminating the Monier and Cottancin systems and reinforced concrete in general, with titles such as: 1891: "Construcções Monier em cimento e ferro", "Contrucções em Ciment e Ferro", "Vigamento de formigão"; 1892: "Construcções com cimento e ferro"; 1895: "Aplicações práticas do ferro e do formigão" and "Os trabalhos de cimento com armadura de ferro – Systema P. Cottancin". In a commentary on Arnaut de Menezes' 1899 article on the comparative analysis of the Hennebique, Monier and Cottancin systems, Augusto Luciano de Carvalho (1838–) discusses the theories of Edmond Coignet (1856–1915) and Napoléon de Tédesco (1847–1922) (Carvalho 1899). The dissemination continued with a series of articles on the different materials used in reinforced concrete in 1900 under the acronym R. P. in *A Construcção Moderna* (numbers 1 to 4) and by José Maria Mello de Matos (1856–1915) in the same journal between 1900 and 1901 in 29 fascicules. The last 14 fascicules (numbers 33 to 46) are dedicated to an abridged version of the calculations of a beam in reinforced concrete by Louis Lefort (1899). They were followed by the essays by Augusto Vieira da Silva, published between 1901 and 1920 in the journals *Engenharia Militar* and *Revista de Obras Públicas e Minas*. In 1905, the *Gazeta dos Caminhos de Ferro* no. 414 disseminated the results of strength tests carried out in Russia on reinforced concrete slabs, vaults, reservoirs and silos. Texts on structural calculations continued to be published by Mello de Matos in *A Construcção Moderna* during the years 1909 and 1910 (no. 301 to no. 324) – in particular, the calculation of a two-floor building in reinforced concrete under seismic solicitation (Matos 1910). In 1910, in numbers 327 to 336 of the same magazine, a review of the issues VI, VII and IX of the Viennese magazine *Beton und Eisen* from 1909 was translated anonymously into Portuguese under the title "O formigão e o formigão armado". In 1911, the volume *Tabelas Técnicas*, by António Vicente Ferreira (1874–1953), written for the Portuguese Railway Company, was a first attempt at a practical manual for reinforced concrete (Ferreira 1972: 22). This same author aimed to define the graphic documents that should be included in a reinforced concrete construction project (Ferreira 1917: 99, 108, 128).

In the context of education and regulation, this period is characterized by the inclusion of some information on reinforced concrete and its calculation in the educational curricula of engineers and architects. A topic on Armand Considère (1841–1916), "Construcções de Cimento Armado, Experiências de Considère" (Constructions in Reinforced Concrete, Considère Experiences), was included in a module for civil engineers at the Academia Politécnica do Porto as early as 1898. Despite those initiatives, it was only in 1911, by means of Decree no. 1 of 29 May 1911, that the training of architects at the two major Fine Arts schools of Lisbon and Porto (Escolas Superior de Belas Artes de Lisboa e Porto) included a module on mechanics and strength of materials for the first time. An autonomous teaching module on reinforced concrete was only included in the curricula for engineers by Government Decree (no. 2.103 of 25 November 1915) in 1915, which created the course on "Cimento Armado" at the Technical Faculty of Porto University. In 1918, it was the turn of the Instituto Comercial e Industrial de Lisboa (Decree no. 5.029 of 1 December 1918). The practical consequences of these changes were very much determined by the publication in 1918 of the first Portuguese standard on reinforced concrete, the "Regulamento para o emprego do beton armado" (Decree-Law no. 4.036 of 28 March 1918), replacing the French "Circulaire du 20 octobre 1906, concernant les instructions relatives à l'emploi du béton armé" adopted ad hoc only in important public works. The

Portuguese ministerial commission,[16] responsible as of 1916 for the elaboration of the new legal document, stated in their final report (Neves et al. 1917), drafted in 25 April 1917 in the main room of the Association of Portuguese Civil Engineers, that standards from the following foreign countries were taken into consideration (the UK, the USA, France, Germany, Austria-Hungary, Switzerland and Italy), "gathering from each of them what was considered most useful to create a precise and concise regulation" and "taking advantage of some special tests [. . .] carried out in the laboratory of the Directorate for Studies and Testing of Construction Materials". The final layout of the new standard was based on a draft prepared by Augusto Vieira da Silva. The same report advised that "works of public interest (should) always be designed and executed under the responsibility of a Portuguese engineer".

While reinforced concrete was gradually being introduced in the training of engineers and architects, its acceptance by the workers' guilds related to masonry and carpentry faced major obstacles. In fact, during the First World War, when confrontations between government, police and trade unions reached a breaking point in Portugal, with major strikes and even deaths in demonstrations, reinforced concrete was represented by the Federation of Building Workers' Unions as an evil to be combated. Reinforced concrete became yet another cause of unemployment for masons and carpenters, as did the gradual mechanization of many quarrying and stone-cutting operations, the use of segmental vaults with embedded steel beams in floor construction which in Lisbon were known as *gaioleiros* – cage makers – and new types of cladding such as hydraulic mosaics and scagliola. According to the Federation, the latter should be "energetically repudiated with the utmost determination to ensure its complete prohibition from the field of construction" (Ribeiro 1914). In this debate, *O Construtor*, the official newspaper of the Federation, would use the competition for the construction of the statue of the Marquis of Pombal until it came to an end in 1915 to defend traditional constructions in carved stone (Pires & Mascarenhas-Mateus 2021: 517). Throughout 1914 and in issue no. 52 of *O Construtor*, the reasons why the monument was all-important in masonry and why it should be covered in carved stone are stated: it would give work to many stonemasons, no public money would be spent on foreign cement, foreign iron, foreign personnel and "great difficulties and dangers" would be avoided.

This resistance would begin to dissipate after the war period. The end of the First World War, in which Portugal had fought, brought a profound change in the skills of the carpenters and blacksmiths who represented the construction cultures of masonry, carpentry and metal constructions. Reinforced concrete had already begun to have "functional consequences" within the labour market, redistributing functions and skills:

> In an important work there must be auxiliary foremen for each of the different jobs: moulding of the wood, manufacture of reinforcing bars and production of the concrete. [. . .] What is indispensable is to have a practical man for each of the main operations: a carpenter for the moulding, a blacksmith for the irons and a mason for the concrete. We must say that, if the general foreman possesses these abilities, it is not necessary that the carpenter be of the first order, for his work is almost always reduced to sawing and nailing boards, rarely making use of the planer. [. . .] In the same way a blacksmith in the true meaning of the word is not necessary, for what is required of him is to bend, cut, splint, open nails, etc. in bars or rods of iron. [. . .] The mason is also dispensable because servants with practice in mixing cement are sufficient for the manufacture of concrete. With the growing increase of reinforced concrete works, specialized workers begin to appear in these works, executing the different works with speed and perfection.
>
> (Segurado 1923–1925: 525–526)

To finish characterizing this period, we should analyse the symbolic and charismatic qualities (to use the terminology of Wallace, 1977) of the new constructive paradigm that spread thanks to the reputation built up in periodicals and specialized publications at the time. The main qualities of this new material were its ease of execution, its monolithic nature, its plastic capacity to adopt any shape and its great mechanical strength in the case of earthquakes and fire:

> Construction of buildings in Lisbon, Oporto and anywhere in the country and the colonies [. . .] Reinforced concrete constructions. Hennebique [. . .] more solid than of iron, masonry, brick or wood, fireproof and earthquake-proof [Figure 1.1.9].
>
> (Advertisement by Moreira de Sá, *Annuário da Sociedade dos Architectos Portugueses*, 1906)

Figure 1.1.9 Advertisement by Moreira de Sá, the Hennebique system representative in Portugal in the yearly book of the Association of Portuguese Architects (*Annuário da Sociedade dos Architectos Portugueses*, 1906).

Source: Hemeroteca Municipal de Lisboa.

> A reinforced concrete construction is a non-deformable block that can adapt to any movement that is imposed on it [. . .] In San Francisco, as previously in Baltimore, fire has once again highlighted the incombustibility of reinforced concrete.
>
> (“Architectura para tremores de terra”,
> *A Construcção Moderna*, 1907, 224: 250–1)

> It also seems that reinforced concrete construction and the American steel frame systems should be used in the reconstruction of Italian cities (Reggio and Messina), as they were in San Francisco. [It has been proven that one or two houses in Messina, which were built by this process, remained solid] [. . .] and it is certain that in San Francisco, the reinforced concrete and steel buildings held up in both earthquakes and fire.
>
> (“Ruined cities: some problems of reconstruction”,
> *A Construcção Moderna*, 1909, 290: 202–3)

> Reinforced concrete has some characteristic qualities: it is easy to construct, can be adapted economically to any shape, however complicated it may be [. . .] and even to follow the designer’s fantasy; it is resistant to withstand stress, however great it may be [. . .] it is unalterable to external agents and above all it is incombustible.
>
> (“Reinforced concrete and reinforced concrete”,
> *A Construcção Moderna*, 1910, 325: 196–8)

As a reaction to the earthquake of Benavente on 23 April 1909, in May of that same year an article was published in *A Construcção Moderna*, called “A catastrophe do Ribatejo – reconstrução de casas para famílias pobres nas localidades mais prejudicadas” (“The Ribatejo catastrophe: Reconstruction of houses for poor families in the most damaged areas”) (294: 234–236), which presents simple designs for wooden-framed masonry houses to be implemented with the money from a public subscription. In June, the same magazine (no. 298: 270) reviewed the book by the Italian Giuseppe Torres (1872–1935) *La casa antisismica* published that same year, stating: “The author believes that reinforced concrete would be the best material to use, since it is homogeneous and gives the maximum lightness with the minimum thickness”. Also in the same year, and as previously mentioned, a series of texts by José Maria Mello de Matos on the practical methods of anti-seismic calculation of constructions in traditional wooden-framed masonry and in reinforced concrete began to be published. Despite its anti-seismic qualities, reinforced concrete was still considered too expensive, as indicated in a review of an article by the Italian Pasquale Sabatini, published in the magazine *Il Cemento* (A Construcção Moderna, 1909, 305: 35), and difficult to use in new rural constructions in the devastated area of Portugal. However, in 1912, in the report produced by the official commission for the study of the most adequate methods for reconstructing the areas affected by the 1909 earthquake and erecting new buildings in the country, reinforced concrete was advocated for use along with traditional wooden-framed masonry as the best system not only for foundations but also for lintels, floor slabs and cantilevered elements in the façades.[17]

Somewhat contrary to the many qualities of reinforced concrete, the “anomalies” of the new paradigm that might be corrected are pointed out from very early on, in particular the problems of permeability and of steel corrosion in the reinforcements. These concerns are evident in anonymous translations of articles from foreign magazines published in *A Construcção Moderna* with titles such as “Alteration of reinforced concrete by the action of seawater” (Matos 1900), “Preservation of metallic reinforcements in reinforced concrete constructions” (No. 178, 1905), “The decadence of reinforced concrete” (no. 283, 1909) and some more, of which some examples are given below:

> Concrete made with Portland cement and sand, ashes or crushed stone seems to better protect the iron and yet we often see corrosion of the iron involved in concrete. In December 1901 Mr P. C. Pearson, under Mr Norton, began the study of the action of cement concrete on steel.[18]
>
> ("Corrosion of steel used in construction". *A Construcção Moderna*, 1903, 90: 45)

> Destroying agents: a) oxidation of metallic reinforcements; b) electrolysis; c) action of sea water; d) acidity; e) oils; f) alkalis [. . .] Waterproofing: to prevent water from passing through the tingling in works which meet certain conditions, asphalt and tar plasters have been tested, applied directly or on previously prepared sheets.
>
> ("O formigão e o formigão armado". *A Construcção Moderna* 1910, 328: 222; 332: 250–1) – translation of text published in *Beton und Eisen*, 1909)

> Inspection beams, which make it possible to easily and safely assess, on site, whether or not concrete moulds can be removed [. . .] This procedure, which was published in 1903 in the magazine Beton und Eisen, was applied in 1910 in many constructions in Vienna.
>
> ("Accidents in reinforced concrete constructions". *A Construcção Moderna*, 1918–1919, 528: 141; 529: 7)

As regards accidents, in 1919, it was reported that serious structural damage was caused by an intense fire fed by highly combustible materials (paraffin and oil) in a reinforced concrete bridge in the Port of Lisbon built in 1917 on pilings of the same material. The article calls into question the thicknesses of reinforcement covered by regulations and reference works:

> in order to protect the reinforcements against the more or less corrosive action of the waters of the Tagus River they were always covered by a layer of concrete 3 cm thick [. . .] In the beams (and in the piles and props): complete destruction of the part of the concrete layer that protected the metallic bars in all their thickness with partial destruction of the concrete excepting the metallic bars [. . .] on the deck: destruction of part of the protective layer of reinforcement and, about one metre from the outer edge, the appearance of a crack in the entire thickness of the deck [. . .] what happened on the Santo Amaro bridge [. . .] partly contradicts what is more or less established in several treaties and regulations on reinforced concrete constructions.
>
> (CL 1919)

In parallel with the discussion of the mechanical capabilities of reinforced concrete, discussions began on the aesthetics to be given to the new construction system. The first articles reveal the division of opinions between those who advocated the use of concrete in a merely functional way, covered with all kinds of decorations, and those who defended the aesthetic and rational truth of its skeleton and its visible surface:

> The artistic use of steel and concrete is considered a new problem in architectural design. A concrete structure is therefore a structural pillar and beam of thin supports and long spans [. . .] horizontal lines which reveal the floors [. . .] The problem is the infill [. . .] between pillars and the successive floors [. . .] (whose) structure is unimportant and can be achieved by various means, but there is no more reason for it to be revealed than the bones in the hand of man [. . .]

> If the surfaces do not reveal the structure inside [. . .] one can resort to low reliefs or mosaics [. . .] or the insertion of other materials: marble, metal, glass, ceramics embedded in it in patterns [. . .] The aesthetic arrangement of steel and concrete [. . .] demands that one recognizes the lack of relief and the delicacy of the proportion of the construction in relation to the surface.
> (“Artistic expression of steel and concrete”. *A Construcção Moderna*, 1908, 332: 251, translated into Portuguese from a text by the North American Howard Walker, which would have been previously published in the magazine *The Illustrated Carpenter and Builder*)[19]

> Visual concrete – Concrete is a material that has a special character and should not be used to imitate any other material used in construction. One of the most important problems in relation to tiles is the appearance to be given to the apparent surfaces, which must be completely resolved before the material is put into place on the building site. In some constructions it is natural to keep the surface of the coffers as is after demoulding, only removing the evidence of the joints between boards. Whenever possible, plastering should be avoided, because, even when it is done very carefully, after a while it disappears almost completely.
> (“Formigão e formigão armado”. *A Construcção Moderna*, 1910, 332: 251)

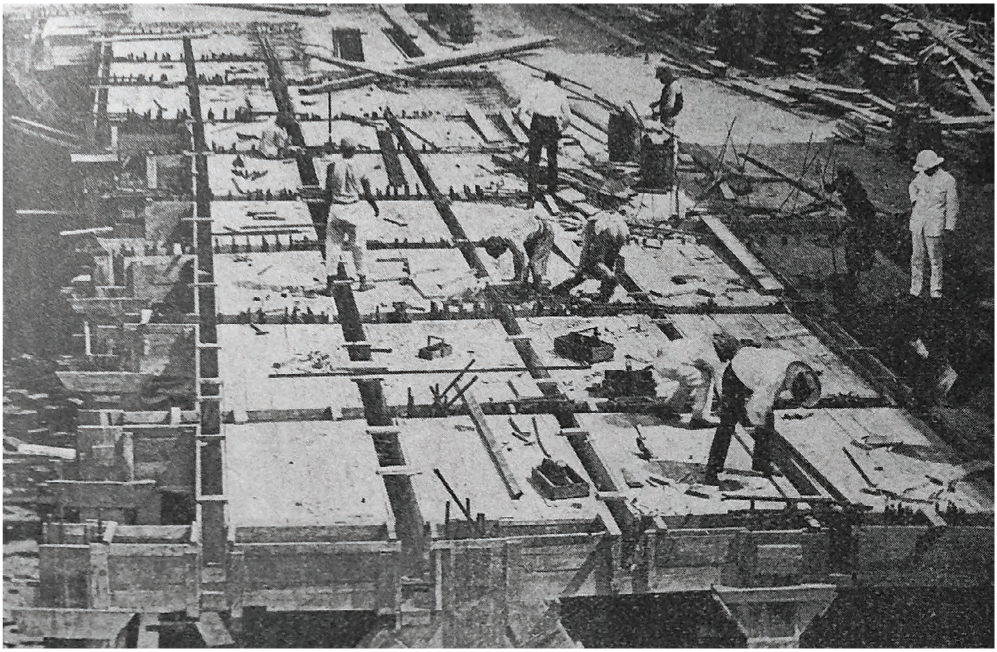

Figure 1.1.10 Jetty under construction, *ca*. 1913, using the Hennebique system with British and German Portland cement by the company L.G. Mouchel & Partners in Lourenço Marques, Mozambique (Veiga 1914: 329).

Source*: Revista de Engenharia Militar*, Military Academy Library, Lisbon.

Consolidation Phase: The Estado Novo Regime and the New Portuguese Regulations on Reinforced Concrete

When the 1926 coup d'état took place, paving the way for the National Dictatorship (1926–1933) and later the Estado Novo regime (1926–1974), the conditions for the use, calculation and teaching of reinforced concrete had achieved legal standardization, albeit incipient, through the publication of the national regulations of 1918. The general public and a considerable number of professionals and contractors had already been able to use the new system in a considerable number of structures, within different aesthetic design agendas. Both the binder and the structural system had achieved an excellent reputation for strength and durability. The primordial experimentation phase was over, and the consolidation period started under the new centralized political regime.

With the (protectionist and interventionist) policy of "Industrial Conditioning" established with Decree no. 19.354 of 3 January 1931), all licences for any industrial activity were transferred to the State, and the three cement companies (located in Alhandra, Rasca-Setúbal and Maceira-Leiria) were "invited to agree on the regulation of the market, creating an oligopoly that lasted until the 1960s" (Confraria 1991: 796). The cement industry was used as a successful model of the application of the regime's "efforts" to modernize the nation. Thus, the facilities created by the owners of the company for their workers (schools, hospitals, holiday resorts, gymnasiums, etc.) enjoyed a wide dissemination among the general public through numerous reports in newspapers, magazines and even postcards. The distribution market for each of the cement plants was divided up by regions with their own representatives and brands, such as Tejo for the southern region and the brand Leixões on sale in the northern region. Large distributors of the whole variety of building materials – such as António Moreira Rato & Filhos and Francisco Henrique d'Oliveira & Irmão in Lisbon and the Companhia de Cerâmica das Devesas in Porto – dominated the market. Others were dedicated to representing specific materials, that is the company Rodrigues, Fonseca & Carvalho from Oporto, which manufactured expanded metal or metal *déployé*. Despite the protection given by the State to cement producers, full acceptance of Portuguese cement for public works was only achieved in 1932. This came about in 1931 following the rejection of *Liz* cement from the Empreza de Cimentos de Leiria (Figures 1.1.11 and 1.1.12) for the construction of a new section of the Port of Lisbon. Not accepting this decision, the three Portuguese cement companies requested an evaluation by three foreign specialists (French, English, and German) of the results of tests carried out on cubes immersed for 4.5 years in the waters of the Tagus River. This evaluation led to the decision a year later to include Portuguese cements in all public tenders for maritime and river works, without restrictions. This important achievement was the subject of a commercial monograph (Empreza 1932).

In this period, new cement derivative industries were also created. The first electric poles in reinforced concrete in Portugal date from 1928 and were regularly produced by the Portuguese Society Cavan from 1932 onwards. Lusalite – Sociedade Portuguesa de Fibrocimento, SARL was created in 1933 and started producing flat and corrugated asbestos cement sheets for roofing, sanitation pipes, and prefabricated houses. In 1938, the same company also produced prestressed electricity poles. Several imported products for waterproofing and water repellents for concrete were advertised, such as the German Ceresit, Leusit, Tricosal and Acosal, the English Pudlo or even the Portuguese Cementite. The increase in demand generated by the public works campaign established by the regime and the new industries deriving from it would cause Portland cement imports to drop to residual levels in 1935.

Figure 1.1.11 Concrete blocks in jetty construction for Figueira da Foz harbour with the Portuguese Portland cement, Liz brand.

Source*:* Empreza (1932), author's private collection.

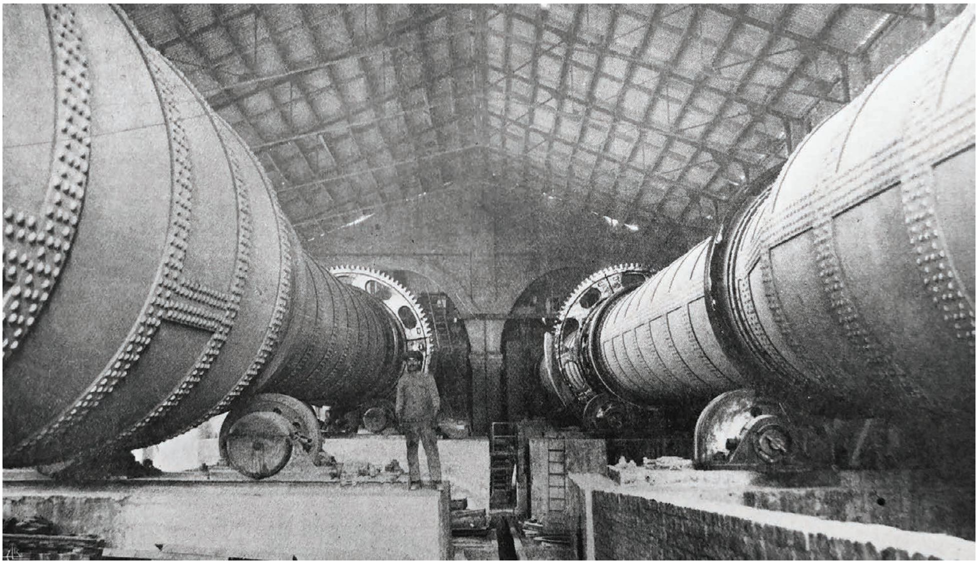

Figure 1.1.12 Rotary kilns in use at the Cimentos de Leiria Portland cement factory.

Source*:* Empreza (1932), author's private collection.

As far as technical dissemination is concerned, it was during the 1920s that the first Portuguese monographs on reinforced concrete theory and calculation were published by Professor Teotónio dos Santos Rodrigues (1891–1955), assistant at the Technical Faculty of the University of Porto when the first course unit on reinforced concrete was created (Rodrigues 1920, 1926) by the engineer João Jorge Coutinho, trained in Valencia, Spain (Coutinho 1923), and by Professor José Belard da Fonseca (1889–1969), who started out as first assistant at the Industrial Institute of Lisbon (Fonseca 1925).

Coutinho's book (Figure 1.1.13) is particularly enlightening, not only in its description of the attempts of these authors to make the theories of foreign theoreticians applicable in practice, but also regarding his own intention to develop solutions to the problem of calculating the effective depth of a beam in reinforced concrete as one of the many aspects still required in the calculation of reinforced concrete structures:

> Having in my possession for consultation the books of illustrious masters of reinforced concrete, such as Espitalier, Magny, Cosyn, Vaubourg, Mesnager, Mörsch, Zafra, Planat and others [. . .] Although reinforced concrete was first introduced in France, it was Germany that first began to make this industry known through the company A. Wayss & C. of Berlin, which created the firm Actien Gesselldsechft für Beton und Monierbau [. . .] Since the theory of the calculation of reinforced cement had a rational bent [. . .] it was seen that this theory was closely linked to the strength of materials and the stability of buildings, and it is then that this genre of construction enters its youth in which, by the way, it is still to be found and which will doubtless continue for many years to come.
>
> (Coutinho 1923: viii, 4, 6)

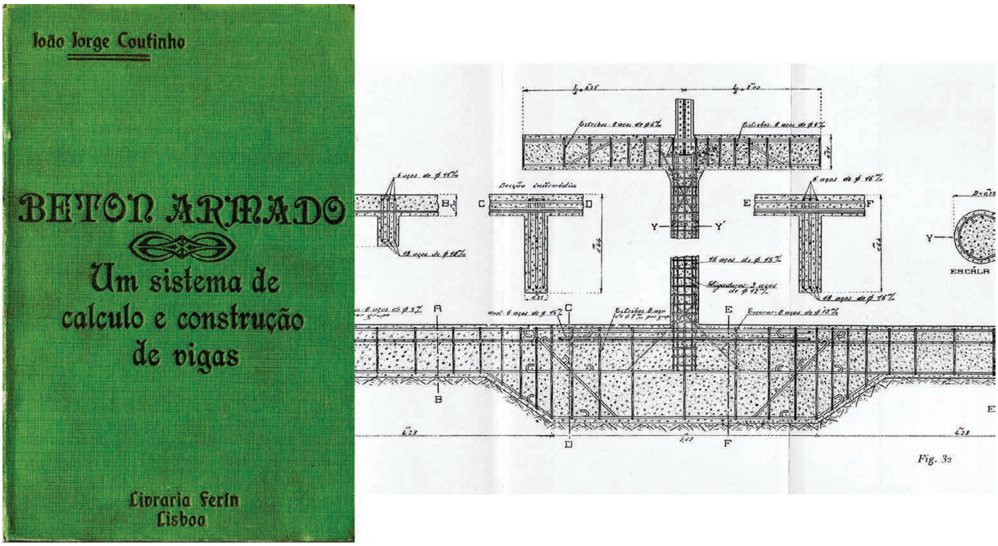

Figure 1.1.13 Cover of the book by João Jorge Coutinho (1923) and detail of the strap footing built to support a new safe for the Banco Industrial Português, in Rua dos Correeiros, 59, Lisbon, used as the practical application of the essay.

Source: The author's private collection.

On the other hand, the book *Cimento Armado* (*Reinforced concrete*) by João Emílio dos Santos Segurado (1875–?), published in the same year, ensured a wide dissemination among both specialized and general audiences of all types of reinforced concrete systems then in use in Europe and in the USA. As regards the publications of formulas for the practical calculation of reinforced concrete elements, it is worth mentioning (Guedes 1925; Oliveira 1929a; Oliveira 1929b; Cohen 1930).

It is also during this period that the first foreign comments on reinforced concrete works made by the Portuguese can be found:

> Abstracts from the foreign press: A Portuguese water tank. Signor Augusto Vieira da Silva of Lisbon, has designed and supervised the erection in that city of a concrete water tank with a capacity more than 80,000 gallons on a support 30 ft high, and with a supplementary tank of 12,000 gallons at the base. The important structural details of the tank do not present any particularly novel features, but it is interesting as it shows the rapid strides made by reinforced concrete in Portugal. *Revista de Obras Públicas e Minas de Portugal*. 1920.[20]
>
> (*Concrete & Structural Engineering*, 1921 (XVI), 12: 820)

At this time, the training of engineers in reinforced concrete was already consolidated in the main schools. In 1926, reinforced concrete was the subject of a course unit at the Escola do Exército (Decree no. 12.704 of 25 October 1926). With Decree no. 19.760 of 20 May 1931, a course on Graphic Statics, Strength of Materials, Steel Construction, Reinforced Concrete and Topography was started at the Fine Arts schools of Lisbon and Porto. In 1935, it would be the turn of the Instituto Superior Técnico in Lisbon, the largest engineering school in Lisbon, to finally offer a course unit on reinforced concrete.[21]

Besides the control of the cement industry market by national companies, technical dissemination and the training of engineers in the calculation of reinforced concrete, as an authoritarian regime, the New State would regulate all the economic, social and cultural aspects of the new construction system. Reinforced concrete was gradually stipulated by law in different types of works. Article no. 31 of Decree no. 13.564 of 6 May 1927 required that only non-combustible materials be used for the construction of new theatres and cinemas. In 1928, the National Fund for Constructions and Economic Rents (established by Decree no. 15.289 of 30 March 1928) started to encourage the construction of new buildings for rent made of reinforced concrete (Vicente 1946: 15, 40–41). The 1930 General Regulation of Urban Construction for the City of Lisbon required the licensing of new buildings, projects and structural calculations for all buildings to be signed by civil engineers or technical engineering agents, imposing the use of non-combustible materials such as reinforced concrete in the floors of wet areas such as bathrooms, kitchens and balconies (article no. 51) and in staircases (article no. 55). This legislation would be responsible for the construction of volumes entirely in reinforced concrete where the wet areas were located at the back of the buildings, popularly referred to as "cod tails". However, the fact that there was no requirement for structures to be made entirely of reinforced concrete meant that, until the Second World War, buildings made of "slabs" (*de placa*) became very popular. Those buildings had reinforced concrete slabs floors simply supported on masonry walls in the façades and interiors.

In 1930, the first specifications for the production and delivery of Portland cement – *Caderno de Encargos para o Fornecimento e Recepção do Cimento Portland normal – Normas de produção e utilização do cimento Portland* (Decree no. 18.782 of 28 August 1930) – were prepared by the Laboratory for Testing and Studying Materials, reorganized in 1915 and then directed by Duro Sequeira. Finally, in 1935, and influenced by the debates held at the First International Congress on Concrete and Reinforced Concrete held in Liège, in 1930, the new Portuguese Regulation for Reinforced Concrete was published (Decree no. 25.948 of 16 October 1935), based on the comparison of all existing European and American legislation.[22] The new code set out on its first page the reasons for its existence and what had changed since the publication of the first regulation of 1918: the results of collaboration between building sites and laboratory, the improvement in the quality of cements, the appearance of new types of high-strength or quick-setting cement, a greater knowledge of the relationship between the composition of concrete and its physical properties, advances in the theory and practice of the strength of materials and advances in steelmaking. Based on a comparison of the regulations in force in Germany, the USA, Italy, France, Belgium, the UK, Hungary, Austria, Denmark, Switzerland, the Netherlands and Russia, the new code limited only the preparation of projects and the direction of reinforced concrete works to civil engineers. The supervision of major works was limited to Portuguese civil engineers.

To respond to these new demands, contractors presenting themselves as specialized in reinforced concrete constructions became common, such as Teixeira Duarte (1921), Sociedade Construtora de Cimento Armado (1930), OPCA (1932), Amadeu Gaudêncio (1933), SETH (1933) or Bernardo Moniz da Maia (*ca*. 1930). In the field of engineering projects, different professionals consolidate their design offices in reinforced concrete, such as José Belard da Fonseca, the Sociedade Engenheiros Reunidos in Porto, created *ca*. 1930; Carlos Craveiro Lopes Couvreur (1905–1993); Augusto Vieira da Silva; Bernardo Moniz da Maia (1900–1988); José de Queirós Vaz Guedes (1902–); Francisco Correia de Araújo (1909–1981); João Barbosa Carmona (1892–1958) and António Ferrugento Gonçalves, to name those most often referred to in publications of the time (Anonymous 1936).

In addition to requiring reinforced concrete in various types of new construction, institutionally and legally, the Estado Novo also sought to impose an aesthetic in accordance with the nationalist "politics of the spirit" – proposed by António Ferro (1895–1956), an important ideolog of the regime – in an enlightened period for Portugal:

> The proofs of this resurgence, this renaissance, are not literary images, rhetorical figures: they are living documents, of stone and reinforced concrete, scattered throughout the country, within everyone's reach.
>
> (Ferro 1933)

Books aimed at the Portuguese middle classes, such as *A Nossa Casa* (first published in 1918) or *A Casa Portuguesa* (1929), both by Raul Lino (1879–1974), contributed to the dissemination of this spirit of creating a nationalist style. These works proposed a traditional style with certain well-defined elements such as porches and pitched roofs with ceramic tiles. This current would be followed by architects recognized by the regime, such as the Rebello de Andrade brothers, Guilherme (1891–1969) and Carlos (1887–1971), and others such as Manuel Joaquim Norte (1878–1962) who saw reinforced concrete merely as one construction process of many capable of creating a structural skeleton to be "dressed" in art-deco, neo-baroque or historicist revisitations.

However, at the same time, various editions of Segurado's (1923) book promoted reinforced concrete as a system with "an extreme malleability, capable of being adapted to all the forms that the needs or whims of the architect and engineer could imagine, regardless of their complexity". The description of the plastic capacities of reinforced concrete was also made in periodicals such

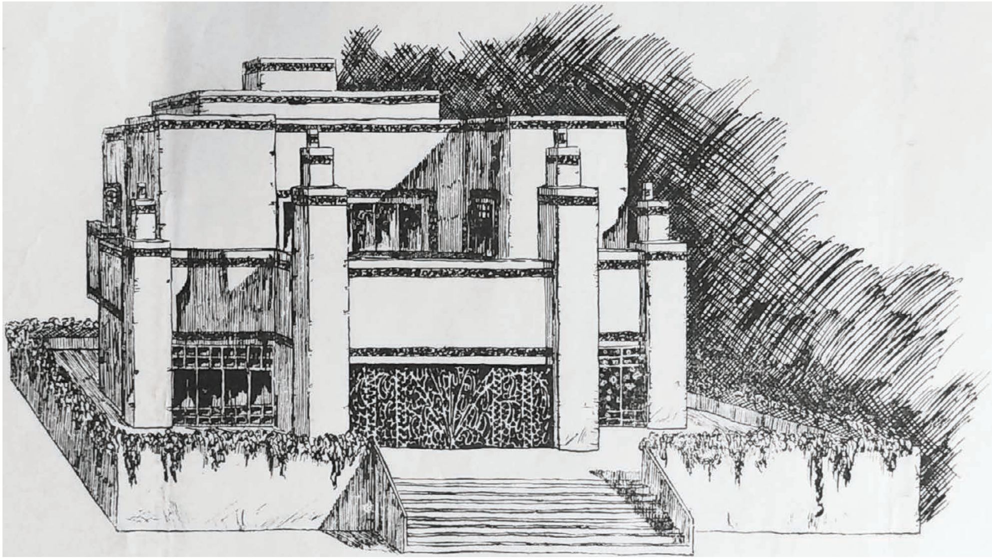

Figure 1.1.14 Project for a private house in Lisbon by José Carlos Sellerier (1927a).
Source*:* Ordem dos Arquitetos Library, Lisbon.

as the magazines *Architectura* and *A Arquitectura Portuguesa*. They contained a veiled debate between the aesthetics desired by the regime and those happening abroad. Thus, the engineer José Carlos Sellerier, referring to the presentation of his project for a villa in exposed reinforced concrete with different shades of colour achieved with coloured gravel (Figure 1.1.14), states:

> Today in Portugal the taste for the so-called Portuguese house, traditionalist and characteristically national, dominates. The style of these houses, simple, cheerful and charming is the one which has resulted [. . .] from the various decorative elements found [. . .] in the rustic houses of our countryside or in the palatial houses of the 18th century [. . .] This style is only rarely suitable in buildings of great proportions, in monuments or palaces, and has no logical connection with reinforced concrete construction [. . .] For these constructions we will therefore have the new style which has already been so well studied and perfected, so commonly applied already in many countries.
>
> (Sellerier 1927a: 26–27)

This current includes several architects who began to seek a certain stylistic emancipation, approaching the presentation of the structure and skeleton of reinforced concrete constructions in a constructive and rational manner, partially revealing the accuracy of their calculations.

Examples of this approach include the architects Luís Cristino da Silva (1896–1976) and Cassiano Branco (1897–1970). Between 1925 and 1929, Cristino da Silva designed the Cine-Theatre Capitólio, a paradigmatic example of the understanding of the aesthetic possibilities of the new system: a large span covered with a thin slab that supported a public terrace, lines that delineated the structural transmission of loads and large openings in the façade. The same would be applied in other projects such as the Beja High School (1930–1936). In the same vein, Cassiano

Branco designed the Rios de Oliveira Automobile Stand, the Eden Cine-Theatre (1927–1937) and the Hotel Vitória (1934–1936), all in Lisbon. This new language, strongly promoted by the Exposition Internationale des Arts Décoratifs et Industriel Modernes in Paris in 1925, would be put into practice in buildings designed by other architects such as Carlos Ramos (1897–1969) for example, the Radio Pavilion at the Instituto Português de Oncologia in Lisbon (1927–1933), the Instituto Superior Técnico in Lisbon (1927–1941) by Porfírio Pardal Monteiro (1897–1957), the Garagem do Comércio in Oporto (1928–1932) by Rogério de Azevedo (1897–1969), the Casa da Moeda (1930–1940) by Jorge Segurado (1898–1990), the Lota de Massarelos (1933–1935) by Januário Godinho (1910–1990) and the Estoril Post Office (1934–1940) by Adelino Nunes (1903–1948).

As demonstrated, and despite the socio-political constraints, at the outset of the Second World War, the new culture of reinforced concrete was firmly established in Portugal. There was a national cement industry that boasted the most up-to-date kilns and processes; a network of importers and distributors of rebar steel profiles; an education system for engineers, architects and builders that included training in reinforced concrete; a reinforced concrete code reflecting all the European and USA regulations and production and reception standards for Portland cement. A reputation had been created and disseminated as to the superiority of Portland cement and reinforced concrete over stone and brick masonry.

Like a tree that is planted, the new culture consolidated its roots, put out new branches, diversified and grew stronger. After the Second World War, the cement industry and the culture of reinforced concrete construction went through new phases determined by the creation of new types of cement, kilns and manufacturing methods; increased production in colonial areas; the introduction of prefabricated beams, pillars, walls and slabs and the advent of prestressed concrete and the diversification of reinforced concrete derivatives. Legally, design competences were to be divided between engineers and architects.

The first three phases analysed in this text were the starting point for all these transformations after 1935 and caused fractures in the way of building in Portugal, constituting an echo – and at the same time cause and result – of what was happening in Portland cement and reinforced concrete in Europe. They are historical moments that radically shaped Portuguese construction.

Conclusion

The reception in Portugal of the new construction culture of Portland cement and reinforced concrete can be analysed in three initial phases. These cover a period that clearly started in the second half of the 19th century, partly overlapping the dissemination of the iron and steel building culture already started at the end of the 18th century, particularly boosted by steam and the industrial revolution, among other major factors. The phases need to be analysed from different perspectives or aspects of a building culture: improvement of theoretical and practical knowledge of raw material production, calculation and laying of materials and structures; technical and commercial dissemination; the building materials market; transfer of knowledge and teaching; legislation; the network of actors involved including the State and its institutions; labour and the corporate status of engineers, architects, contractors, labourers, producers and dealers of building materials and the works built and the technical solutions adopted. This cross-cutting examination of the changes to everyday ways of building resulting from an adaptation to the specific Portuguese cultural conditions that took place in less than a century allows us to conclude, among other things, that the image of these new materials and construction process also suffered successive transformations among academia, the productive sector and the general public.

In the initial phase, when the old paradigm of masonry and carpentry was called into question, natural and artificial cements and the concrete produced with them were seen as construction processes capable of overcoming many limitations and were non-combustible, with great mechanical strength, highly durable, economic, using raw materials that were never exhausted, easy and fast to execute without the need of skilled labour, economical and so on. In other words, this was a revolutionary construction process capable of adopting any desired shape, with unlimited strength for use in public works, and capable of solving the problems of providing healthy housing for all social classes, both in rural and urban areas.

In the intermediate phase, the consensus achieved around the reputation built in the first phase is partly questioned and focuses on a smaller number of aspects, with little transparency towards the general public. Since its advent, reinforced concrete had been analysed not only in terms of its advantages but also in terms of its limitations. Thus, the problem of reinforcement corrosion, for example, began to be tested mainly in maritime works. The need for coatings based on petroleum derivatives to ensure waterproofing was discussed. The answer to these limitations was stricter demands on projects, calculations and execution. However, the First World War would "validate" reinforced concrete constructions with the highest strength ever attained.

In the consolidation phase, national cements were unquestionably accepted for all types of public work – even maritime works – and their production was sufficient for almost the entire national consumption. Reinforced concrete also became fully present in economic and institutional structures. The discussion about the limits of the materials and the construction process would now be the preserve of the academic and professional community. For the general public – which includes most of the potential customers of the materials and construction processes – the reputation created in the initial phase would remain unshaken for lack of alternative materials and processes.

Notes

1 The Portuguese article published in May 1835 in Lisbon is the full translation of an anonymous French article (Anonymous 1835a) published in March of that same year in the *Journal des Connaisssances Utiles*, a scientific journal founded in Paris in October 1831 by the Société Nationale pour l'Émancipation Intellectuelle created by Émile de Girardin (1802–1881), like the preceding one created in London by Henry Peter Brougham (1778–1868), the Society for the Diffusion of Useful Knowledge.

2 Roman cement begins to be mentioned in the General Customs Tariff concerning the import duties of the class "Stones, Earth and other Fossils", as of 1841. See *Diário do Governo*, no. 80, 3 April 1841:1.

3 In 1847, a royal decree determined the customs duties to be paid for the import of pozzolana from Italy for the works on the Azambuja canals, since this material was not yet included in the list of customs duty values. See *Diário do Governo*, no. 272, 17 November 1847: 1.

4 Pozzolana from the Azores was first marketed by a network of merchants such as Augusto Ferin, Figueiredo & Irmão, Magalhães & Filhos, Germano Serrão Arnaud or Guilherme Arnaud. See letter Augusto Ferin 1862–04–14 (ref: PT/BPARPD/EMP/BF/001–003/000069) in the digital archive of the Secretaria Regional do Governo dos Açores.

5 See *Diário de Lisboa*, 21 March 1867: 822. Francisco da Ponte e Horta was a professor at Polytechnical School in Lisbon.

6 The company created in 1873 incorporated the mines of the Empreza das Minas de Carvão e Indústrias do Cabo Mondego, which already had at least one flare kiln on this site since 1801 (Ávila 1853: 6).

7 Some of these names are still used today for the reinforcement of reinforced concrete.

8 Several bridges were built by this company founded in 1874. The catalogue presented by Portugal at the Universal Exhibition in Chicago mentions as works of the Empreza Industrial Portuguesa the metal decks on masonry pillars of the bridges of the Guadiana, Zêzere, Esposende, Vila do Conde and Mosteiró (Carvalho 1896: 301, 304).

9 This laboratory resulted from the research initiated by the ministerial commission nominated in 1866 to study the strength of construction materials, as already mentioned. The laboratory would be succeeded by a (national) directorate, the Direcção dos Estudos e Ensaios de Materiais de Construcção, within the Ministry of Public Works, in 1898. The laboratory of this directorate was directed by engineer Castanheira das Neves.

10 Reinforced concrete had variously been known as *formigão armado*, *ferro-cimento*, *sydero-cimento* and *cimento armado* since the first publications in the last decade of the 19th century. The name *betão armado* (reinforced concrete) became stable in the 1930s with the publication of the 1935 regulations.

11 Portuguese patent no. 1678 entitled "Works in plastic material with frame or skeleton made of a metal net" is dated 27 April 1892 and was valid for 15 years.

12 Portuguese patent registration no. 2108 (Class XII), requested by Jacq Monet, resident in Lisbon, on 30 November 1895 on behalf of François Hennebique, in the Book of Patents and Trademarks, states: "A light and high strength beam, made of cement concrete, with iron bars and stirrups embedded in the mass". The registration had a duration of four years. Hennebique registered two other patents in Portugal: one for pipes, pillars and concrete joints (no. 4560, filed on 22/2/1904; issued on 7/7/1904) and another for prefabricated elements, such as tiles and beams (no. 4618 filed on 30/04/1904).

13 Licença de obra (building permit) no. 101/1898. Document/Process, 1898/03/19–1898. Documents: PT-CMP-AM/PUB/JOP/203/101.1898; PT-CMP-AM/PUB/CMPRT/OM/203/101.1898

14 Peres would go on to publish reinforced concrete projects in the *Revista de Engenharia Militar*, such as the foundation system of a building in Lisbon in 1911 (Peres 1914a) and to criticize the limits of the French Circular of 1906 (Peres 1914b).

15 "For current works there are three qualities of cement: Portland, natural and pozzolanic or scoria; in the case of reinforced concrete, only the first must be used only and exclusively". ("O formigão e o formigão armado", *A Construcção Moderna*, 1910, 329: 229).

16 The commission was composed by some of the Portuguese "pioneers" in the use of reinforced concrete already mentioned: J. P. Castanheira das Neves, João Lino de Sousa Galvão Junior, José Joaquim Peres, Augusto Vieira da Silva, António Vicente Ferreira, Raul Miguel de mendonça and António Carlos d'Aguiar Craveiro Lopes.

17 The commission was made up of representatives of the Ministry of Public Works, associations of civil engineers and architects and professors of civil and military engineering. The document entitled "Instruções para as novas construções, reconstruções ou reparações dos edifícios públicos e particulares, nas regiões assoladas pelo terramoto de 3 de Abril de 1909 ou por outros anteriormente registados" was published in the *Boletim da Associação de Condutores de Obras Públicas*, 1912: 38–55.

18 In addition to this article, another disclosure article is published the following year with the title: "Corrosão nas armaduras de aço nas construcções". *A Construcção Moderna*, 134: 11.

19 Consulting the 1907 and 1908 issues of the *American Carpenter and Builder*, it was only possible to find an article entitled "The Artistic Treatment of Concrete" by A. O. Elzener, in the February 1907 issue.

20 The news in *Concrete & Structural Engineering* probably refers to the two water tanks made in 1917–1918 by Augusto Vieira da Silva when the former Campolide College in Lisbon was adapted to a military hospital (Dias 1951: 18).

21 Paradoxically, the course unit was only created after a formal request from first-year students to the School Council of the Instituto Superior Técnico (*Técnica* 1934, 59: 438).

22 On the composition of the commission created to elaborate the new code, see Delgado and Pinto (2016).

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Chapter 1.2

From Patent to Standard

Accommodating Change in Britain's Use of Building Materials, 1824–1934

Edwin Trout

In Britain, a simple glance at the building's culture of either end of the period under review is more than sufficient to indicate great change. The humble country cottage and elegant Regency town house lining a London square are a world away from the car showroom and aircraft hangar, or the skyscraper and Art Deco cinema that typify the early 1930s. It is clear that in building, as in so much of European material culture, there has been a huge technological and cultural shift. What became possible in structural design and construction stemmed from the introduction of new building materials – not just their invention but also their acceptance and adoption by the construction industry and the society it serves: a change in the "culture of building".

Building practice at the start of our period, in the 1820s, was traditional – vernacular – rooted in local materials and methods. But 19th-century Britain was industrializing rapidly, and a greatly increased output of manufactured bricks and quarried stone was needed to meet the needs of an ever-growing population, through distribution first by canal and later by the railway. And in an urban explosion of new towns and cities, an eclectic and derivative approach to architecture led to a "battle of styles" between the proponents of various historical revivals in an apparent clash with the use of emerging modern materials such as iron and glass. Just look at the juxtaposition of London's St Pancras railway station and the mock gothic hotel next door! Our interest here is in the case of a third material, Portland cement (first developed in the UK), its early use in concrete and later extension into reinforced concrete under the influence of foreign example.

The chronological outline is well recorded, so this study will seek to identify "landmarks" in the narrative that suggest how, and to what extent, the introduction of Portland cement changed British building practice and then find parallels in the story of early reinforced concrete in the UK.

Portland Cement

The Patent

Customarily an invention from which commercial gain is sought is protected by the process of patenting, allowing the inventor to benefit exclusively from its commercialization over a period of years. Our review commences in 1824 with the patenting, by Joseph Aspdin (1778–1855), of a material he called Portland cement (Figure 1.2.1). This was a loosely defined material, the patent specifying little of practical use either in the proportioning of constituent materials or in its manufacture. The British patent No. 5022, granted to Aspdin in 21 October 1824, noted:

DOI: 10.1201/9781003368656-4

Figure 1.2.1 Joseph Aspdin's patent for Portland cement, 1824.

Source: Concrete Society photo library.

> I take a specific quantity of limestone such as that generally used for making and repairing roads, after it is reduced to a puddle or powder; but if I cannot procure a sufficient quantity of the above from the roads, I obtain the limestone itself and I cause the puddle or powder, or the limestone as the case may be, to be calcined. I then take a specific quantity of argillaceous earth or clay and mix them in water to a state approaching impalpability, either by manual labour or machinery. After this proceeding I put the above mixture into a slip pan for evaporation, either by the heat of the sun or by submitting it to the action of fire or steam conveyed in flues or pipes under or near the pan, until the water is entirely evaporated. Then I break the said mixture into suitable lumps and calcine them in a furnace similar to a limekiln till the carbonic acid is entirely expelled. The mixture so calcined is to be ground, beat or rolled to a fine powder and is then in a fit state for making cement or artificial stone. This powder is to be mixed with a sufficient quantity of water to bring it to the consistency of mortar and thus applied to the purposes wanted.

Significantly, however, Aspdin chose to name it after Portland stone, then used principally as ashlar for prestigious masonry buildings. Paradoxically, his new product was rooted in tradition;

even the association with Portland stone had been made by earlier pioneers of cement – Bryan Higgins (1741–1818), John Smeaton (1724–1792) and William Lockwood (1781–1865). It is probably fair to say that Aspdin's new cement, which he proceeded to produce in Wakefield, in the northern county of Yorkshire, found initially little favour and was confined to a geographically limited market in his own locality. Its impact on the culture of building was negligible, other than as an example of a topical interest in cements. The prevailing binders were traditional quicklime and the relatively recently introduced "Roman" cement that was based on calcining *septaria*, naturally occurring agglomerations of chalk and clay.

Early Use

Early cements were used largely for enhancing decorative stucco and for waterproofing mortars applied to buildings and hydraulic engineering works: harbours, locks and lighthouses. Most notably, Roman cement was used to bed the brickwork in the Thames Tunnel, a significant engineering project in Georgian London. Project engineer Marc Brunel (1769–1849) went as far as to say: "I have no hesitation in saying thaat in the construction of the Tunnel we cannot introduce any other substance but Roman cement of the best quality" (as cited in Francis 1977: 46).

In order to broaden its appeal as the basis of concrete – which was usually bound with lime – the new cement makers turned to building their own homes in concrete as a demonstration of their product's potential. A number of these houses are to be found in Kent, Suffolk and Somerset. The earliest of these, built in 1835 by John Bazley White (1848–1927) at Swanscombe (Figure 1.2.2), was the subject of the very first paper addressed to the Royal Institution of British Architects (RIBA), "The Nature and Properties of Concrete" by George Godwin, who was later the editor of *The Builder*. It

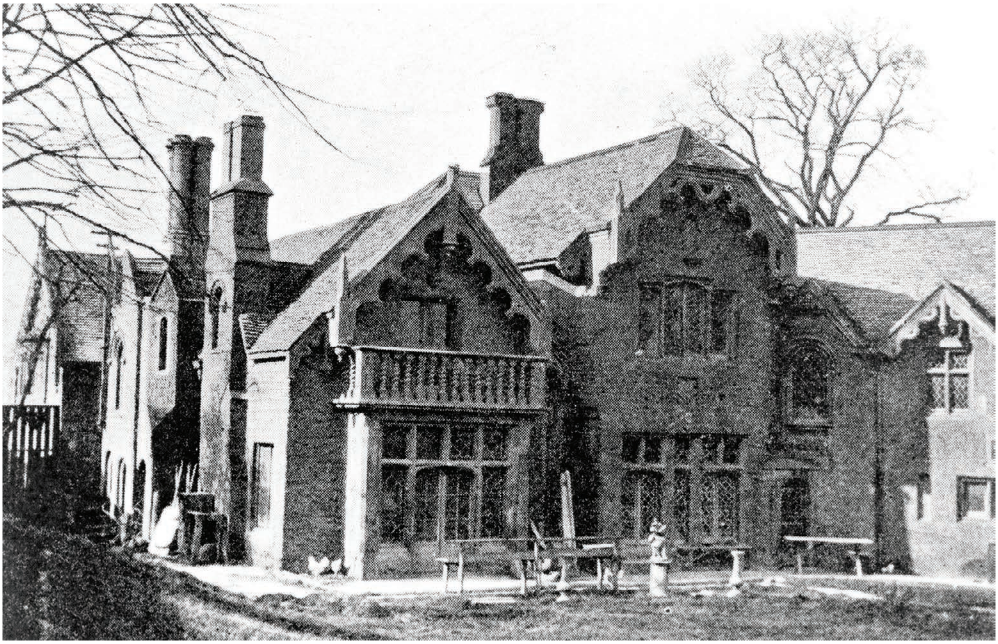


Figure 1.2.2 John Bazley White's concrete house at Swanscombe, 1835.

Source: Concrete Society photo library.

is perhaps telling that no further papers considered cement-based concrete at the RIBA until the late 1860s when there was a brief revival of professional interest in concrete architecture.

Trade Publicity

Cement itself, however, became a subject of increased interest during the 1840s, as new production processes led to improved material properties. In July 1841, Joseph Aspdin's son William (Figure 1.2.3) left the Wakefield works and made his way to London, whereupon he set up

Figure 1.2.3 William Aspdin.

Source: Concrete Society photo library.

business as a cement maker at Rotherhithe at a works owned by J.M. Maude, Son & Co. William Aspdin (1815–1864), a rather self-confident character, had some knack for publicity. In the summer of 1843, he announced that Portland cement was being introduced to the London market, highlighting "improvements introduced in the manufacture" and claiming that "it is stronger in its cementive qualities, harder, more durable, and will take more sand than any other cement now used" (as cited in Francis 1977: 111–112). Whether by accident or design, "overburning" (or clinkering) had been found to improve strength.

Comparative Trials

It was not long before this new Portland cement was put to the test. In 1843, the contractors rebuilding the Houses of Parliament, Messrs Grissell & Peto,[1] undertook comparative trials of this and existing Roman cements. They summarized the results in a letter of 13 November, acknowledging "very satisfactory evidence of the superiority of your cement" (as cited in Redgrave 1895: 29 and in Francis 1977: 113). Mixed with three parts sand, Portland cement was more than double the strength of Roman (Figure 1.2.4). Positive publicity and some influential advocacy followed shortly afterwards – picturesquely described at the time as "the flourish of trumpets that was then being made about the new cement" (as cited in Johnson 1909 and quoted in Francis 1977: 113). It was sufficient for rival firm J.B. White & Sons to enter the market and, led by its chief chemist, Isaac Charles Johnson (1811–1911), independently discover the necessity of clinkering in 1844. Other manufacturers soon followed.

Not only enjoying third-party endorsement, Portland cement also benefited from the threat of shortages of alternatives and the introduction of taxes to protect diminishing supplies of the

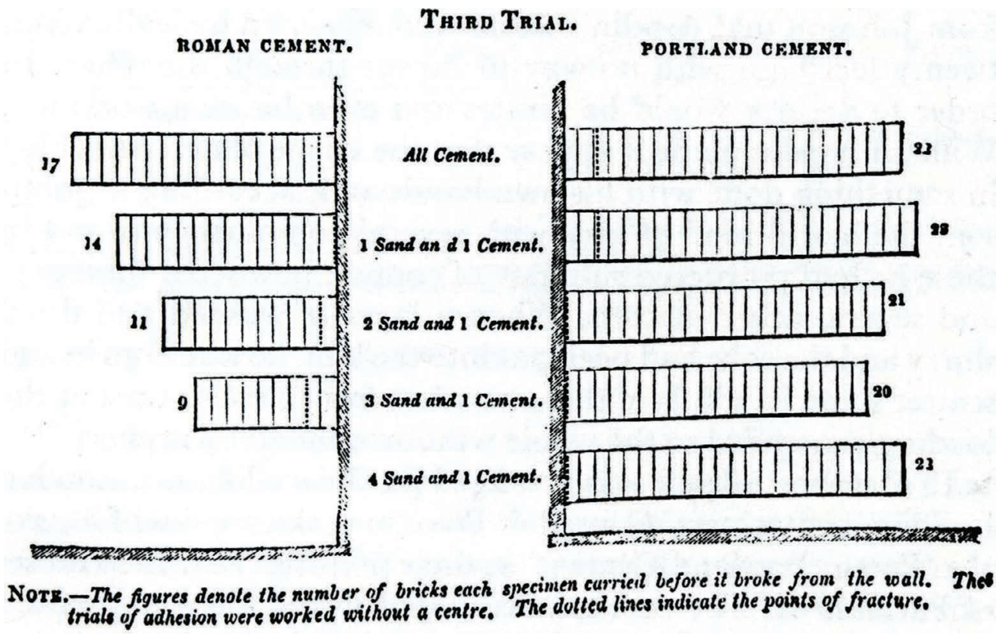


Figure 1.2.4 Results from Grissell and Peto's trials of Roman and Portland cement.

Source: From a report of 1843, reproduced in Francis (1977).

Figure 1.2.5 The Great Exhibition, 1851.

Source: Contemporary illustration reproduced in Francis (1977).

raw materials for Roman cement production. Aspdin actually discouraged these by suggesting to the Government that such cements would soon be made obsolete by his new Portland cement. Lower price per unit of strength and increased availability, combined with a well-publicized building site disaster at London's Euston in 1848, all served to undermine the previous dominance of Roman cement. Portland cement was becoming a serious competitor.

Exhibiting to the Public

The Great Exhibition of 1851 (Figure 1.2.5) was an opportunity to display industrial output before the general public and encourage a greater awareness of the successes of British manufacturing. Conceived by Prince Albert (1819–1861) as a high-minded attempt at "industrial education", a World's Fair showing off the best in the decorative arts and manufacture and developing public taste, the scheme was eventually housed in a magnificent crystal palace designed by Joseph Paxton (1803–1865). It was a novel structure in cast iron and glass, executed on a vast scale. It also had concrete rather than wooden foundations and housed exhibits from the emerging cement, concrete and cast stone industries.

Competing for precedence, prestige and profit, Aspdin and Johnson's respective companies embarked on a series of comparative tests, and both made use of the Great Exhibition to enhance and publicize their reputations. The report made by the exhibition jurors stated:

> Messrs Robins, Aspdin & Co are exhibitors of a gigantic slab of Portland cement measuring 20 feet by 10 feet and 10 ins thick weighing 15 tonnes; numerous blocks of cement and concrete proved to various pressures up to 154 tons and showing the strength to be

> greater than that of Portland stone; of bricks cemented together and placed so as to give a pressure of 3 tons on the first brick; and of several other similar illustrations. The Jury have awarded a prize medal to these Exhibitors as showing specimens on a very large scale admirably illustrating the use, strength and other capabilities of the material they manufacture.
>
> (as cited in Francis 1977: 118)

Johnson's employer, John Bazley White & Sons, attempted much the same. Exhibits included a wall panel illustrating the use of Portland cement as stucco; a "beam of tiles laid in Portland cement adapted for flooring"; part of blocks of concrete made for Dover and Alderney harbours, and the breakwater at Cherbourg. Both companies undertook tests (Figure 1.2.6) aimed at proving the strength of Portland cement, and, having seen the results, the Jury declared "they fully prove the value of the peculiar material known as Portland cement, and its great advantage over the Roman or Parker's cement".[2]

Established Uses

Describing Portland cement in 1852, the producer George Frederick White (1816–1898) identified its three main uses: as stucco, brick-laying mortar and blocks for harbour walls, piers and breakwaters. Seven years later, reinforcing comments by George White

Figure 1.2.6 Remains of test sample from a demonstration by Bazley White & Bros at the Great Exhibition.

Source: *Cement Age* (13): 243.

(1851–1852: 478–502), John Grant (1819–1888) reiterated: “Up to this time Portland cement had been confined to ordinary building operations such as external plastering and a few harbour works on the south coast where it was most used in the form of concrete blocks” (Grant 1875: 1).

Professional Interest

White had been addressing the Institution of Civil Engineers, by then 30 years old and the country’s senior engineering body. The very fact of White being invited to speak, and indeed of his and other cement makers’ election to membership, indicates a growing acceptance of cement’s value by the professional establishment. This was mirrored in military engineering when in March 1862, a paper by Captain Henry Scott’s (1822–1883) entitled “On concrete as a substitute for brick and stone masonry in works of fortification” was read at the Royal Engineers’ Establishment, Chatham, advocating the Army’s use of Portland cement in concrete construction (Scott 1862: 220–239; Trout 2016).

Quality Control Introduced

Such advocacy found practical expression when in 1859 Portland cement was first accepted for use in a large-scale public engineering works: the London Main Drainage that replaced London’s woefully inadequate, ad hoc drainage arrangements with a systematic solution (Trout 2019a). Three main sewers were proposed for each side of the Thames, designated the high, middle and low intercepting sewers. The low sewers were to be fitted with pumping stations to raise the flow of discharge to a height suitable for gravity to convey it to outfalls along the River Thames at Beckton and Crossness: “Previous to 1859, Roman cement was, with few exceptions, the only cement used for the inverts of the London sewers; the arches being set in blue lias lime; Portland cement was scarcely ever used” (Grant 1875: 1).

Portland cement was largely untested, half as expensive again as Roman, and sensitive to variations in production by “an industry where production control and quality control process were still rudimentary” (Halliday 1999: 150). However, its hydraulic nature and strength increase over time made it an obvious choice for consideration. In 1859, project engineer John Grant make an initial investigation, with 302 experiments conducted between January and July on cement supplied by 12 manufacturers. Cubes of neat cement and mortar were immersed for 10–14 days and crushed; other samples were made into briquettes and subjected to tension (Figure 1.2.7). Roman cement withstood 200 lb of pressure; Portland 600 lb.

Therefore, on Grant’s recommendation, Portland cement was specified under Contract 1 for laying the brickwork in the northern high-level sewer. Following further testing, however, the specification became more demanding, cement density increasing from 106 lb to 112 lb, and every batch was to be tested for strength before use[3]:

> The whole of the cement for these works, and herein referred to, to be Portland cement, of the best quality, ground extremely fine, and weighing not less than 112 lb to the imperial bushel. It is to be bought on to the works in a state fit for use, and is not to be used therein, until it shall have been up on the ground for three weeks at the least, nor until it has been tested by taking samples out of every tenth sack, at the least, gauging these samples in mounds, and by apparatus similar to those heretofore in use by the said Board, placing the cement at once in

> water, in which it is to remain for several clear days, and testing at the end of that time by the application of a weight or level. All cement that shall not bear, without breaking, a weight of five hundred pounds, at the least, when subjected to this test, shall be peremptorily rejected and forthwith removed from the works.
>
> (as cited in Halliday 1999: 152)

This specification for acceptance by the client introduced what was to be the first systematic scheme of testing for quality control in the cement industry. Portland cement was similarly specified for the Government's naval contracts after 1867, when tests at Chatham dockyard confirmed Portland cement's superiority over hydraulic lime and pozzolana (Bernays 1879–1880).

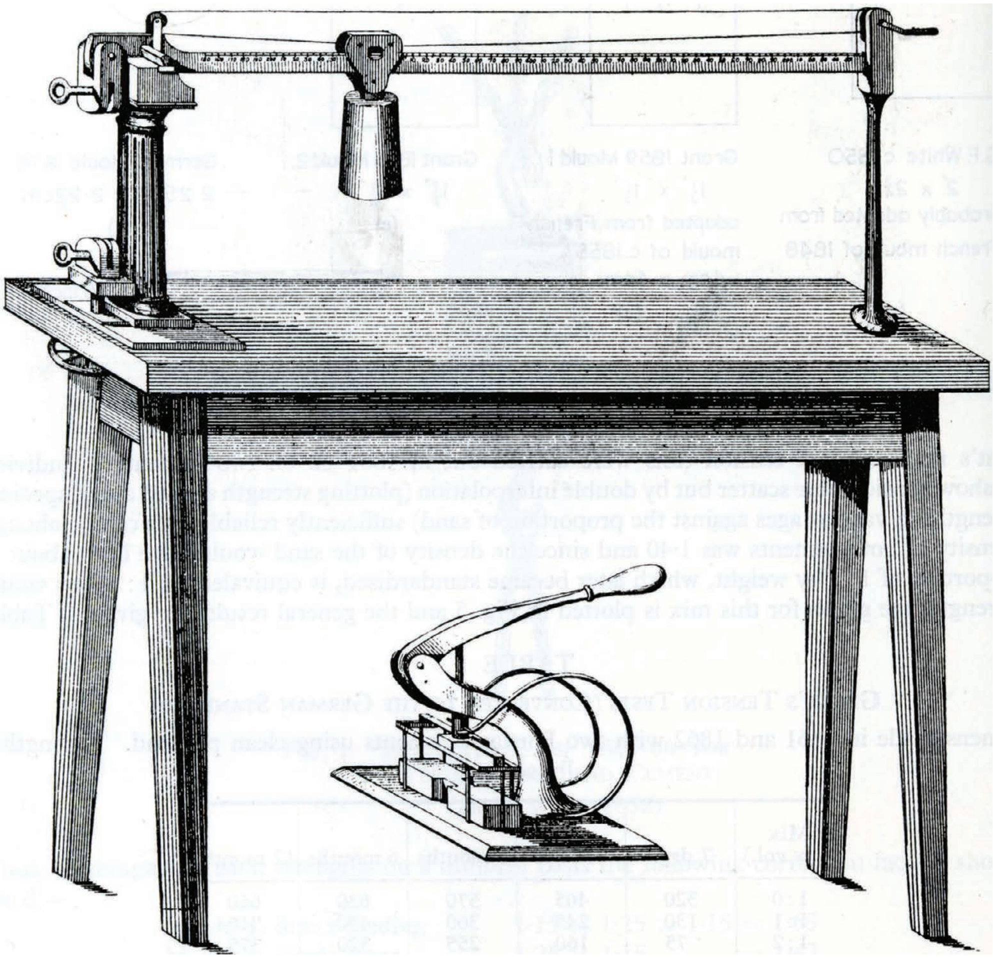


Figure 1.2.7 John Grant's equipment for testing the tensile strength of Portland cement.

Source: Grant, "Experiments on the strength of cement", *Minutes of the Proceedings of the Institution of Civil Engineers* (25): 66–111; reproduced in Reid (1868).

In-Situ Concrete Adopted for Building Purposes

The year 1867 also saw a significant step forward in the use and acceptance of PC-based concrete for building purposes, with the introduction of patented systems of reusable formwork as an aid to its effective and economical placement. These developments came to public attention at the Paris Exhibition of 1867:

> There are several so-called systems of concrete construction, from the older mortar and gravel mixture to the more recently prosecuted one of Portland Cement, in varying proportions with gravel or shingle; of the latter, successful results have been arrived at under the auspices and patronage of his Imperial Majesty the Emperor of the French. Visitors to the late Paris Exhibition had the opportunities of convincing themselves of the value and advantages of this particular method of construction.
>
> (Reid 1868: 86)

Such systems allowed for the reassembly and reuse of a limited number of panels within a framework of supports to erect walls in continuous progression and, when complete, move on to the next building.

According to Thomas Potter (1894), the first in Britain was one patented in 1865 by Joseph Tall, who "brought the use of monolithic cement concrete walls into much prominence by the introduction of wood frames or moveable panels for casting the concrete" (as cited in Barfoot 1976: 26). The system comprised an arrangement of vertical wall forms with scaffolding platforms bracketed to them in the horizontal plane. These sections were used in pairs, secured in parallel by tie bolts running through the resulting wall. Tall was one of the exhibitors at the Paris Exhibition and was awarded a gold medal for his apparatus (Figure 1.2.8).

Napoleon III was sufficiently impressed with Tall's system to order 40 workmen's houses to be built in the Boulevard Daumesnil, in Paris:

> The Emperor has, on the advice of Mr. W. E. Newton, the English engineer, adopted for the forty new dwellings of which I have already given the form of concrete construction which will remedy almost entirely the common default of the damp walls of the first set of buildings erected by him and give him the advantage of all the model dwellings in the Exhibition in economy and quality of wall construction. [. . .] For the Emperor's new dwelling there was used a movable case, invented by Mr. Joseph Tall, with which the walls may be constructed very quickly to any height, with considerable gain in time.[4]

However, despite approval in the French capital, the London authorities were not so receptive. "The desired and necessary support to ensure success in a novelty like this does not yet seem forthcoming", suggested Henry Reid (1825–1883) months later (Reid 1868: 86). London's latest building regulations were founded on the Metropolitan Building Act 1855 which codified established practice: "Walls constructed of brick, stone or other hard and incombustible substances", the regulations required and firmly stated that "every wall constructed of brick, stone or other similar substances, shall be properly bonded and solidly put together with mortar or cement" (as cited in Harper 1976: 28). This was the rub, as officials contended that concrete could not be said to be properly bonded and solidly put together. Although the Metropolitan Board of Works carried out tests in November 1867 in Gravesend, which clearly demonstrated the superior strength of PC-bound concrete, buildings with concrete walls were permitted only

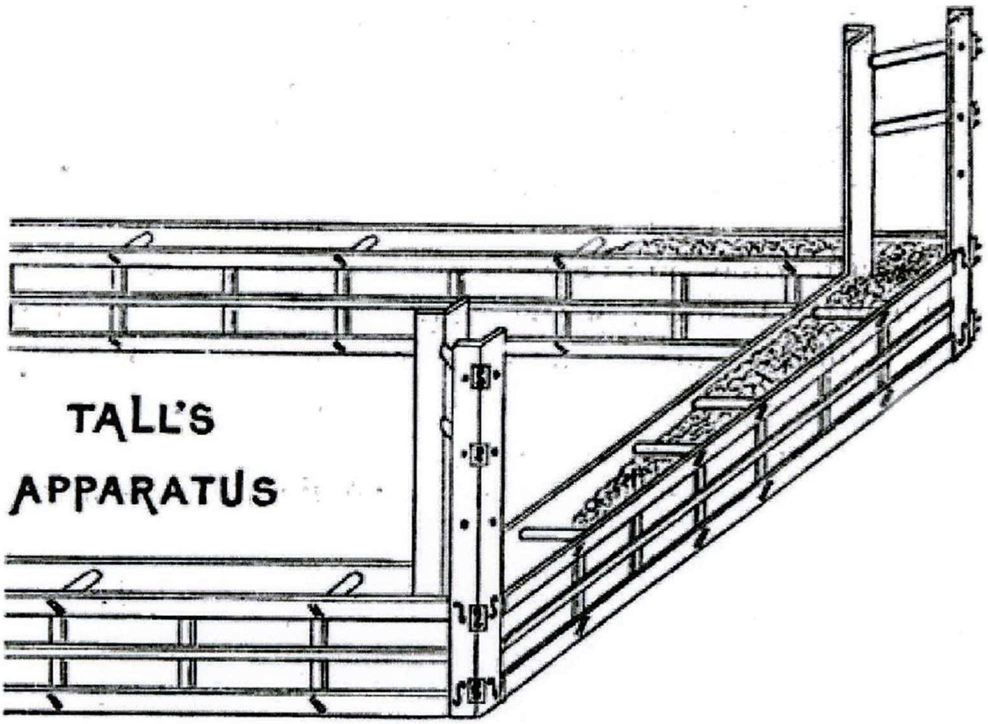


Figure 1.2.8 Tall's patent apparatus, 1865.

Source: Potter (1877).

by special licence. The first was in February 1868 in which the contractor H. Goodwin, using Tall's system, built what he claimed to be the first cement–concrete building in London: a 60 ft-high warehouse in Great Guildford St, Southwark.

For others, however, the Paris exhibition prompted an interest in concrete construction for social benefit, as an effective and economic means of improving the accommodation of the working classes. In this, they were led by Edwin Chadwick's (1800–1890) "Report on Dwellings Characterised by Cheapness Combined with the Conditions Necessary for Heath and Comfort", which appeared in the *Illustrated London News* in July that year (Chadwick 1867: 26).

The twin themes of economy and sanitation were to recur again and again in the press coverage of the time.[5] Evaluations such as "a much larger cottage at a less amount of money" and "will not be anything like the price of a brick or stone one" were most often encapsulated as "half the cost of brickwork", sometimes adding there would be little in the way of repairs.

It should also be realized that heavy demand for bricks in railway construction, for the London Main Drainage project and the boom in housebuilding, had "caused bricks and bricklayer's labour to be inordinately scarce and dear" and that in the five-year period 1862–1867, the cost of building materials (with exception of timber) had doubled and wages risen 33%.[6] This then gave impetus to arguments for cheaper construction methods, though would also undermine them if the cost of brickwork were to fall (Reid 1869: 94).

The advantages of concrete, as rehearsed by contemporaries included:

- economy – half the cost of brickwork;
- sanitation – freedom from damp and vermin;
- insulation – deadening the sound between houses;
- only one (or sometimes no) coat of plaster required;
- no lintels or arches required for openings;
- no bond timbers required as joists.

Not to mention the occasional reference to fire-resistance.[7] So with these advantages in mind, and given Chadwick's and William Edwar Newton's (1818–1879) endorsement, 1867 proved to be a turning point, as the evidence of concrete's economy and improved sanitation was publicized in the press. (Indeed, it is notable how few references to concrete for housing appear in the newspapers prior to 1867.) By 1869, concrete housebuilding (Figure 1.2.9) was, according to the *Builder's Trade Circular*, from 12 August 1869, "somewhat of a novel character, but appears to be gaining ground".[8]

This was especially manifest among the landed gentry with a concern for the living conditions of the rural workforce. Concrete building was to proceed, as is so often the way in the UK, under private speculative enterprise and private patronage, particularly on landed estates in southern England and Ireland or private industrial locations such as colliery villages in Scotland and the north of England. Cheap concrete cottages were an expression of patrician paternalism providing for plebeian inhabitation.

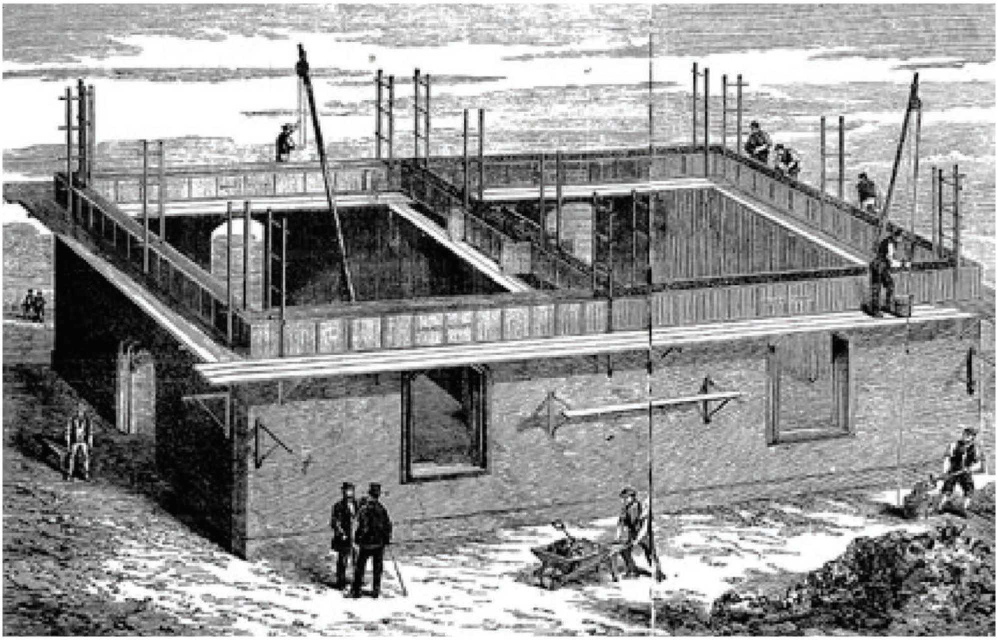


Figure 1.2.9 Concrete house being built with apparatus by Charles Drake (1838–1892), as advertised in Drake's prospectus of 1870 in the book *Concrete Building: By Her Majesty's Royal Letters Patent.*

Source: Drake (1870: 42).

A New Literature Established

In such a climate, it is not surprising that interest was stoked by the emergence of a specialist literature. Most notable of the new writers was Henry Reid (Figure 1.2.10), a consultant of Portland cement producers, who vigorously advocated the use of concrete. He wrote four books between 1868 and 1879 and to judge by a further, privately printed volume of combative rebuttals to press criticism, had quite an impact on contemporary opinion. He was followed by

Figure 1.2.10 Henry Reid: cement maker, consultant and author.

Source: Reid (1877).

Thomas Potter in 1877, clerk of works to one of the leading aristocratic patrons of concrete cottage-building, and John Newman ten years later. These writers represent the start of a specialist literature on practical building that continues to this day.

Regulatory Approval

The combination of interests and influences eventually effected a change in official attitude, and by the late 1870s, concrete construction had become widely accepted. Enabled by the Metropolis Management and Building Acts Amendment Act 1878, new by-laws for its use were duly introduced in 1886. In these, Clause 2a required concrete substituted for brickwork to be "of Portland cement, clean sand, and clean ballast, gravel, broken bricks or furnace clinker, passing a two inches diameter ring, in proportions 1:3:3, carefully mixed with clean water and carried up regularly, in parallel frames of equal height" (as cited in Harper 1976). Concrete had become as a standard building material and no longer had to rely on wealthy clients to promote private projects on their own estates.

Industry Consolidation

Cement as a basic commodity was by now long established and its use in concrete now an accepted application, but the production process was still in a state of evolution. The industry was composed of numerous small enterprises, with fierce competition and low market prices in consequence. During the 1880s, its superiority, in terms of product quality, was ceded to Germany, and by the 1890s its leadership in terms of productivity was being eclipsed by the USA. And around the turn of the century, it was also being beaten on price by Belgium. This was not lost on contemporaries, as mentioned in 1985 Redgrave's book preface:

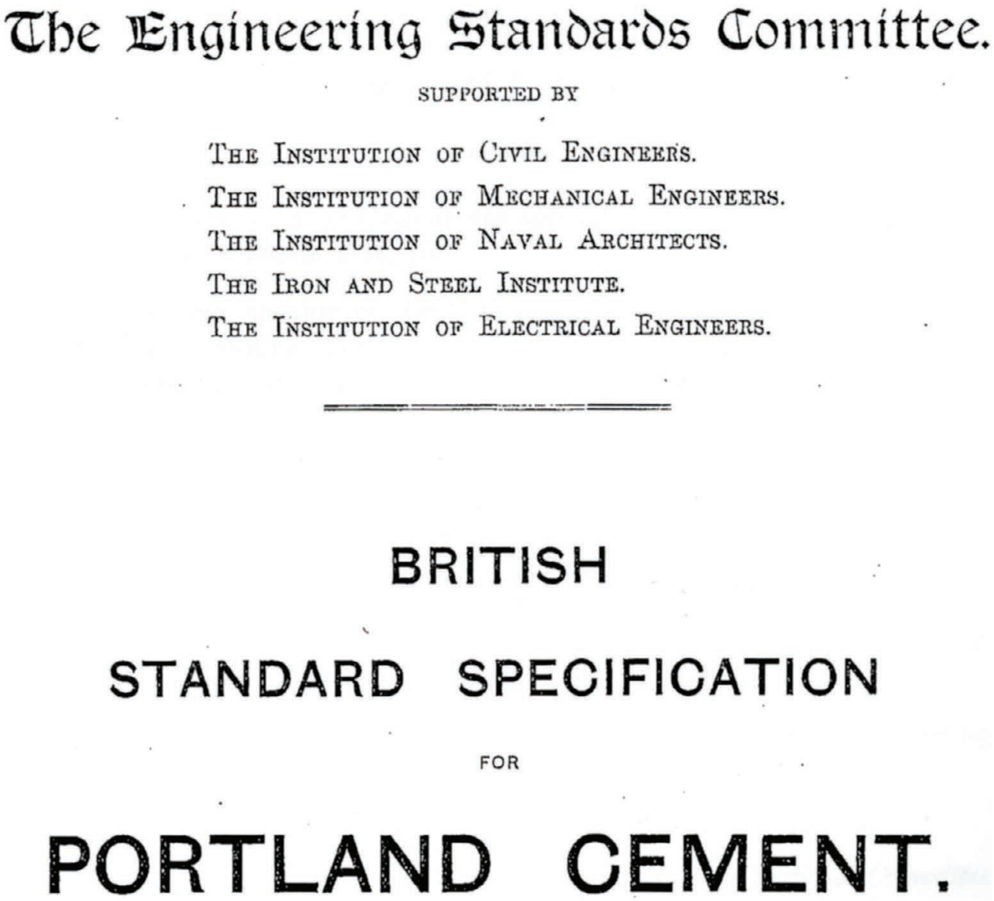
> Our own country, the original seat of the manufacture, has been distanced in certain directions in consequence of the superior scientific skill and the energy of foreign rivals. The supremacy we have so long enjoyed has undoubtedly been to some extent wrested from us by the products of Continental industry and enterprise.
>
> (as cited in Francis 1977: 253)

The UK's response was to consolidate and adopt innovation from overseas. First among these was the introduction of the rotary kiln, equipment that allowed continuous production. Although British designs had been tried out from 1877 onward, it was not until American improvements were patented in 1895 that the rotary kiln became practicable. The first in the UK was installed in 1899. The capital investment required, however, was such that it generated a willingness in the British industry to consolidate. The Associated Portland Cement Manufacturers was formed in July 1900, followed in 1912 by a subsidiary, the British Portland Cement Manufacturers. With around 80% of the business thus combined, a disparate industry was united and ready to respond to challenges from competitors abroad.

Standard Specifications

This unity facilitated agreement on the publication in 1904 of the British Standard Specification for cement: BS 12 (Figure 1.2.11) was, indeed, one of the very first standards in Britain. This and the aforementioned structural changes set the course for British cement until the end of the 20th century.

The story here is one of gradual exploration of PC's possibilities by British construction, and the improvements in product quality, set against the properties (and availability) of weaker



The Engineering Standards Committee.

SUPPORTED BY

THE INSTITUTION OF CIVIL ENGINEERS.
THE INSTITUTION OF MECHANICAL ENGINEERS.
THE INSTITUTION OF NAVAL ARCHITECTS.
THE IRON AND STEEL INSTITUTE.
THE INSTITUTION OF ELECTRICAL ENGINEERS.

BRITISH
STANDARD SPECIFICATION
FOR
PORTLAND CEMENT.

Figure 1.2.11 British Standard Specification for cement: BS 12, 1904.

Source: Copy of British Standard in Concrete Society library.

alternatives such as blue lias lime, Roman, British, selenitic and slag cements. The "push" came from manufacturers seeking new markets. Acceptance comes from testing, proving, exhibiting and use. The standard illustrates this well: derived from a long experience of tests, it required testing for quality control and is itself a statement of quality expected. However, by the time of its introduction in 1904, Britain had lost its early leadership to Germany, whose standard (and the trade association that promoted it) were introduced in Prussia in 1878 and throughout the German empire in 1887. But catching up in 1899–1904, British cement achieved a quality suited to the 20th-century challenges of reinforced concrete construction.

Reinforced Concrete

We can see parallels in the introduction and development of reinforced concrete, though over a shorter time frame and with greater dependence on foreign precedent. Here, the UK can claim an element of technological leadership, pointing to Wilkinson's patent of 1854, early experiments in the UK by American investigators W.E. Ward and Thaddeus Hyatt during the 1860s and 1870s, and the British-born Ernest Ransome's (1844–1917) founding of a company to make square-section iron-reinforcing bars in the USA. Other British and American patents were lodged by W.H. Lascelles (1832–1885): 1877; J.J. Jackson: 1877; J.C. Golding: 1884; W.H. Lindsay: 1885; William Simmons (1885–1886); Lee & Hodgson: 1885 and W.H. Briggs in 1889 (Kempton Dyson 1910: 765). But the truth is, none of these early developments made any significant difference to the culture of building in Britain. They were left unexploited or were commercialized overseas. The innovations to have most effects on the emergence of reinforced concrete in Britain were French.

The Influence of French Patents in the 1890s

The system patented by Joseph Monier (1823–1906) in 1867–1877 was licensed for use in the German and Austro-Hungarian empires during the 1880s, and while it had little impact in Britain, the later patents of Monier's compatriots in the 1890s most certainly did, laying the foundations for reinforced concrete's adoption in the UK.

Edmond Coignet (1853–1915) was awarded a patent for reinforced concrete pipes and tunnels in 1890. His proposal of reinforced concrete for the Paris drainage system was accepted in 1892 and proved to be something of a catalyst; his patent for beams was published later in 1892. Another for piles and sheet piles followed in 1894. That year also saw Armand Considère (1841–1916) commence his research into columns that led the application of spiral reinforcement for concrete in compression. But it is with François Hennebique (1842–1921) and the exploitation of his 1892 patent that we are mainly concerned here. In seeking to attribute the commercial success of reinforced concrete in the 1890s, the Scandinavian engineer and professor at the Technical University, Edouard Suenson (1877–1958), identified the contribution of two men above all: "the engineer Wayss in Germany and the contractor Hennebique in France" (Trout 2015). In the original Danish, Hennebique is described rather as "Entreprenor", which is probably a more germane description, and it was his commercial dominance in multiple European markets, including Britain, that directed reinforced concrete's development for a decade.

The First Reinforced Concrete Frame Building in Britain

The first reinforced concrete frame building in Britain was Weaver's Mill in Swansea (Figure 1.2.12), built in 1897–1898. This came about through the involvement of Louis Gustave Mouchel (1852–1908), a French businessman resident of Briton Ferry, who imported ore from Brittany and exported Welsh coal by the return trade. Given his involvement in cross-channel shipping, he acted as vice-consul responsible for the ports of south Wales, organizing French ship movements in Swansea and neighbouring harbours. This activity brought him into contact with Hennebique, who had established an agency in the French port of Nantes. Mouchel (Figure 1.2.13) engaged Hennebique's organization to carry out designs for the extension of his works and was apparently sufficiently impressed that he introduced the representatives of Weaver & Co to Hennebique in 1897 and was instrumental in persuading them of the merits of reinforced concrete for their proposed provender mill.

While the mill was erected in 1897–1898, Mouchel accepted an appointment as Hennebique's general agent for the UK. This business, operating under an exclusive license, was formalized as "Mr L.G. Mouchel, General Agent, Hennebique's Patent Construction in Ferro-Concrete". It dominated the design of British reinforcement for a decade.

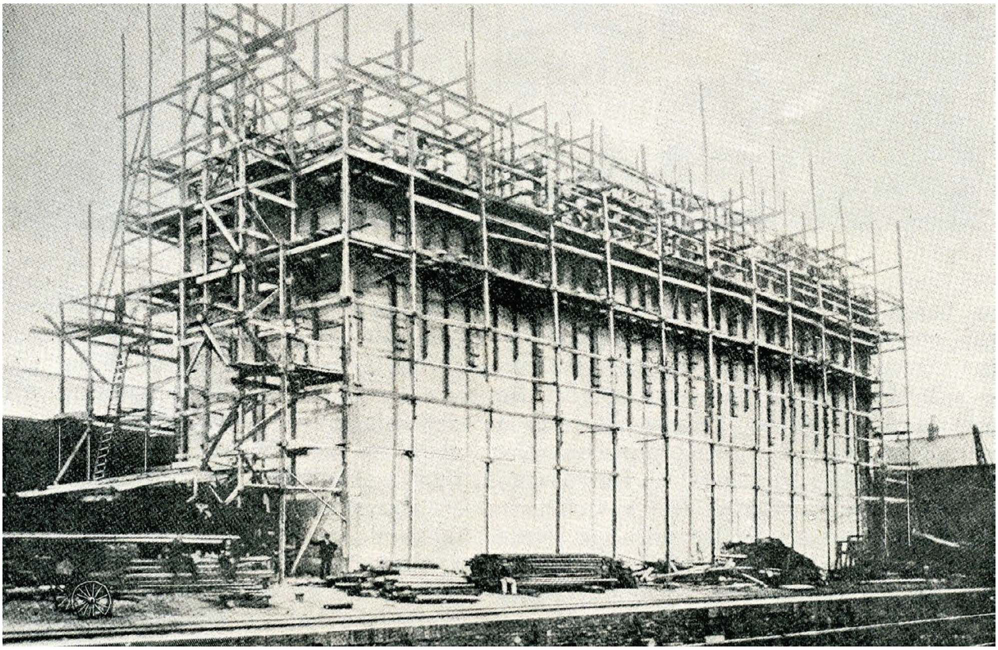


Figure 1.2.12 Weaver's Mill under construction, 1897.
Source: Heidenreich (1897).

Figure 1.2.13 Louis Gustave Mouchel (1852–1908).
Source: Concrete Society photo library.

Table 1.2.1 Key Early Works in Mouchel's Ferro-Concrete, along with the Date of Contract for Reinforcement Design

1897	Weaver & Co's provender mill, Swansea (first reinforced concrete frame building in the UK)
1897	Retaining bank, Southampton (Mouchel's first contract as a general agent)
1899	Woolston Jetty, Southampton; 136 × 100 ft (first reinforced concrete jetty built in the UK)
1900	Dagenham jetty (first use of patented cylinder-protected piles)
1900	CWS warehouse, Newcastle-on-Tyne
1900	Meyrick Park water tower, Bournemouth (first reinforced concrete water tower in the UK)
1901	CWS grain silos, Dunston-on-Tyne; 14 ft × 45 ft (first reinforced concrete grain silo in the UK)
1904	Cold store, Southampton (largest in the world at the time, founded on 1,000 piles)
1904	Coal bunker, Park Royal, London (first reinforced coal bunker in the UK)
1904	Newton-le-Willows water tower, Lancashire; capacity: 300,000 gallons (largest in the world at the time of construction)
1905	Waterford Viaduct, Waterford Quay, Ireland; 720 ft long, on piles 62 ft long
1907	Ouseburn river conduit, Northumberland; 33 ft wide, half a mile long
1907	Circular grain silos, Dunston-on-Tyne; 46 ft × 72 ft deep (first circular silos in the UK)
1907	General Post Office, London
1908	Royal Liver Building, Liverpool (first British "skyscraper")
1908	Stakeford highway bridge, Northumberland
1908	Brooklands motor racing track, Weybridge

An Expanding Market

Between 1897 and 1899, only seven Hennebique-framed buildings were commissioned in Britain; but in 1908 alone, there were 40.[9] In 1909, there were some 1,000 reinforced concrete works, most of them commercial or industrial, of which 70% used the Hennebique system through Mouchel's agency. These included over 130 reinforced concrete frame buildings constructed between 1897 and 1908, and similar number for parts of buildings. There were 89 bridges and a similar number of water and colliery works. In each case, Mouchel or one of his subordinates was responsible for designing the reinforcement, acting under the instructions of either client or architect, and supervising the reinforced concrete work.

Active Marketing

Mouchel shared Hennebique's expansionist, entrepreneurial approach, operating along similar lines: patenting designs, letting construction work to licensed contractors, vigorously promoting the Hennebique system through invitations to observe tests, giving lectures and publishing promotional literature. In this, he was very successful, and his obituary in 1908 claimed that "by sheer pertinacity and the manner in which he inspired confidence, [he] obtained the ear of professional men of influence who adopted the system of construction he represented".[10]

Looking back over these years, Alfred Tony Jules Gueritte (1875–1964) evaluated Mouchel's unique contribution in a paper for *Concrete & Constructional Engineering*, "The first decade of reinforced concrete in the United Kingdom (1897–1906)" (Gueritte 1926: 86). L.G. Mouchel &

Figure 1.2.14 Walter Noble Twelvetrees, the editor of *Ferro-Concrete*.

Source: The author's copy of bound volume and photo from the Institution of Structural Engineers, reproduced in Trout (2013).

Table 1.2.2 Leading Patentees of Reinforced Concrete in Edwardian England

Cottancin	In Britain 1902–1906; opening an office in 1904
Monier	Marketed from 1902 by the Armoured Concrete Construction Co. with a British office opened in 1904
Coignet	Mr G.C. Workman appointed General Agent for the UK and in 1904; the firm Edmond Coignet, Ltd established in 1908
Truscon	British patent obtained in 1903; British office opened in 1907
Indented Bar	In the UK, no later than 1907
Considère	British office, Messrs Considere Constructions, Ltd, opened in 1908

Partners' expansionist drive continued after the founder's death, with the magazine *Ferro-Concrete* (Figure 1.2.14) launched under the editorship of Walter Noble Twelvetrees (1853–1941) to promote the company's success and cultivate the market for reinforced concrete.

Other New Systems Introduced

With such a grip on the market, there was an understandable reaction against Mouchel and the Hennebique system by fellow engineers, and other proprietary systems were soon patented. By 1905, there were over 50 such systems in the UK and more than 70 by 1910 (Kempton Dyson 1910: 765). Of these, some of the better-known incoming practices are listed in Table 1.2.2.

The Liberalization of Concrete Construction Before the First World War

In these early years of the 20th century, Mouchel – and the increasing number of specialists with an interest in reinforced concrete construction – had many obstacles to face, including

Figure 1.2.15 Tanner's General Post Office building at the date of construction.
Source: Concrete & Constructional Engineering 1906, 5: 786.

professional ambivalence or hostility, typified by the attitude displayed by Henry Statham (1839–1924), editor of the influential magazine *The Builder*. Not least was the lack of provision for its use – even its proscription – by the Greater London Building Regulations that had been introduced under the London Building Act 1894. In consequence, much of the early adoption was in provincial cities far from London – Glasgow, Hull, Liverpool, Manchester and Newcastle – by self-governing clients such as the co-operative societies, or by the autonomous water boards, dock and harbour authorities and railway companies for civil engineering projects. One client that was free from local authority control was the Government itself, and Sir Henry Tanner (1849–1935), appointed Chief Architect to the Office of Works in 1898, was a well-placed champion for reinforced concrete when he specified it for the new General Post Office (GPO) offices in King Edward Street (1.2.15) and other Post Office buildings elsewhere in London. Built according to the Hennebique system, the King Edward Street building was the first of its type in the capital and for many years the largest (Trout 2020).

Tanner himself commented on the situation:

> There has not been hitherto in this country any authoritative pronouncement on the necessary rules to be observed in such construction. In many ways this has prevented employment of reinforced concrete, such employment being practically prohibited for complete buildings

> under the ordinary building rules and regulations; and it is only those bodies who are free from this restriction, such as railway and dock companies, who have been able to avail themselves of so economical and space-saving a method of construction, and on these points, I speak from experience.
>
> (Tanner 1907: 513)

The path to broader acceptance was not a straight one, but the commercial confidentiality that surrounded these largely foreign systems acted as a spur to independent research and publication by members of the professions. The principal staging posts along the way are described in the subsequent sections.

1904: A Technical Literature Established

Archibald Constable of London published the first British textbook on the subject, Charles Fleming Marsh's *Reinforced Concrete* (Figure 1.2.16). This went through several editions and was hugely influential. It initiated a specialist literature that was dominated in the pre-war years by a handful of British writers such as Twelvetrees, Rings, Dunn, Coleman, Cantell and Andrews, alongside American authors published in the UK.[11]

1906: Legal Status Clarified

Litigation dismissed proprietary rights to reinforced concrete: Mouchel successfully sued Cubitt & Co for a breach of licence terms in 1906 and took his rival Coignet to court in a long-running case for patent infringement. The latter initially went in Mouchel's favour, only for the Lord Chief Justice to pronounce that reinforced concrete was a "discovery", rather than an "invention".

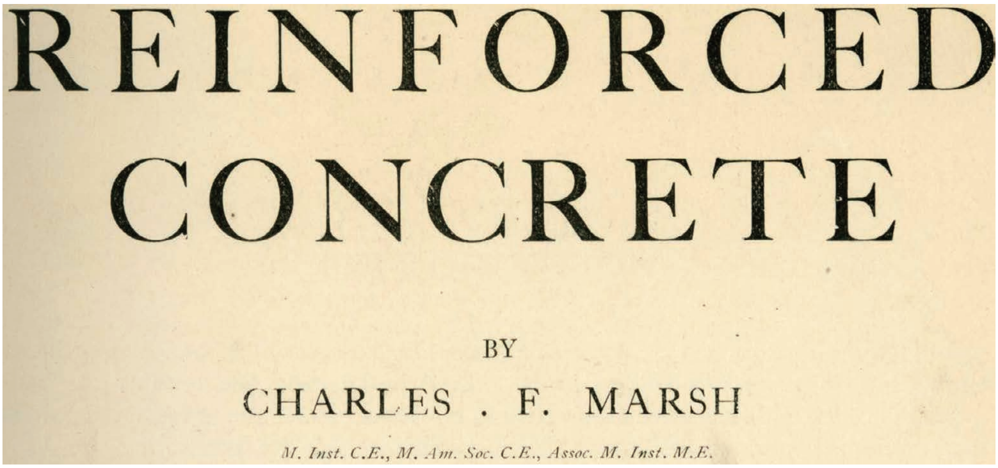


Figure 1.2.16 The first British textbook on reinforced concrete design, 1904.

Source: Concrete Society library.

1906: Best Practice Shared

Architect Edwin Otho Sachs (1870–1919) launched *Concrete and Constructional Engineering* (C&CE) to promote and make available overseas experience of reinforced concrete construction (Figure 1.2.17 and Figure 1.2.18). The monthly journal was to be: “a reliable digest of the world’s latest information” with the “latest scientific data from pens of undoubted authority” (Sachs 1906: 2; Trout 2005: 65–86).

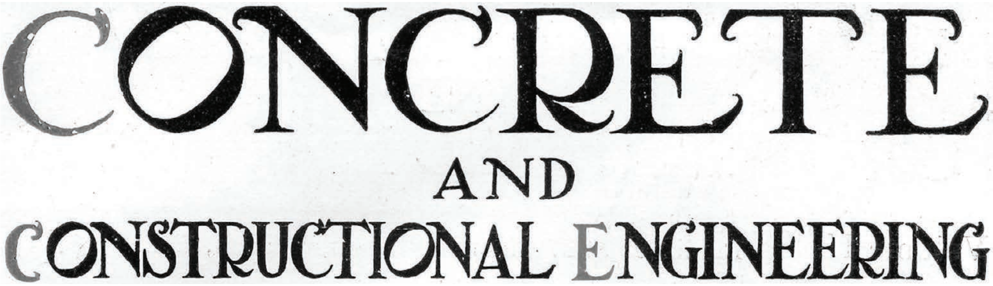


Figure 1.2.17 *Concrete and Constructional Engineering* launched in 1906.

Source: Concrete Society library.

Figure 1.2.18 E.O. Sachs, editor of *C&CE* and founder of the Concrete Institute.

Source: Concrete & Constructional Engineering, 51 (1) 2.

1907: Professional Guidance Proposed and Developed

The Royal Institute of British Architects published the first report of its Committee on Reinforced Concrete, chaired by Sir Henry Tanner, which proposed "rules for the guidance of architects for the use of reinforced concrete" (Tanner 1907). Marsh was also a member of the committee, as were representatives of a wide range of interested parties. In 1910, the Institution of Civil Engineers issued a preliminary report on reinforced concrete, and in 1911 the RIBA issued a further report, proposing a common form of notation.

1908: A Specialist Institute Founded

The Concrete Institute was founded by Sachs as a technical body to promote the free development of reinforced concrete and, in part, to counter the restrictive, commercial interests of specialist patentees.[12] Regular meetings with papers by leading exponents, followed by erudite debate between peers, were reported verbatim in published transactions. These, with *C&CE*, constituted a useful corpus of professional knowledge. Sir Henry Tanner served initially as Vice President, and from 1910 as President.

1909: Legislation Enacted

The London Building Act was amended to permit regulations on reinforced concrete in line with recommendations made by the RIBA and Concrete Institute.

1912: Research and Education

The first university research into reinforced concrete to be published in Britain (Figure 1.2.19) was prepared by Oscar Faber (1886–1956) and Percy George Bowie (1889–) (Faber & Bowie 1912). Evidence of teaching reinforced concrete at university and the technical colleges started

Figure 1.2.19 Presentation copy of Faber and Bowie's *Reinforced Concrete Design*, 1912.
Source: Concrete Society library.

to appear in print at this time, with books by educationalists such as Mark Cantell (1869–) in Brighton and Nathaniel Martin (1884–) at the Royal Technical College, Glasgow.

1915: Regulations Issued

After the London County Council (LCC) issued draft Regulations for comment in 1910, the principles of reinforced concrete design were finally codified for British practitioners when in 1915 the LCC issued its *Regulations relating to reinforced concrete and steel framed buildings*. They were widely adopted throughout the UK (Figure 1.2.20).

Ironically, it was the demands of a war which saw British use of reinforced concrete compared directly with that of France and Germany, which brought about its full acceptance as an essential building material – perhaps nowhere more so than in the Government issuing of contracts for reinforced concrete shipping in 1917 (Figure 1.2.21). By this date, concrete was taking the place of rival materials.

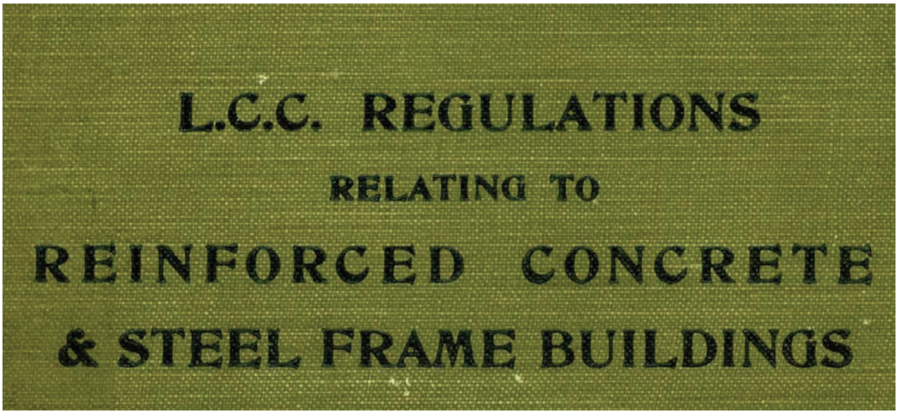


Figure 1.2.20 Title page of Ewart Sigmund Andrews' (1823–1956) guide to the LCC's Regulations, 1915.

Source: Concrete Society library.

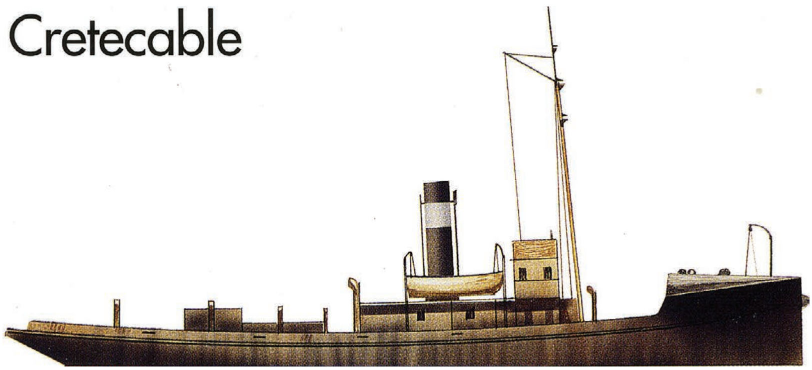


Figure 1.2.21 The *Cretecable* built in 1919 in Shoreham, West Sussex.

Source: The Review of the Reinforced Concrete Association, 1936.

Changing Professional Roles

Curiously, the interchangeability of materials was reflected in changes to the professional body that represented expertise in reinforced concrete design: the Concrete Institute. In 1923, recognizing that the role of the engineer was becoming more of an independent consultant in the design of structures, and the niche of consulting structural engineer was being carved out by the likes of Oscar Faber and Albert Burnard Geen (1882–1966), the Concrete Institute was transformed into the Institution of Structural Engineers. The introduction of reinforced concrete was having an impact on professional relationships as well as construction. This affected architects too. We have seen that much of the lead in devising design guidance for reinforced concrete was taken by the RIBA, but by the late 1920s, engineers such as Owen Williams (1890–1969) started to act as architects too. In this way, Williams designed the Dorchester Hotel (1928–1930), the Daily Express Building (1928–1931), the Boots "Wets" factory (1930–1932) and Empire Pool (1933–1934).

Acceptance of Reinforced Concrete as a Medium for Architecture

Indeed, architecture's response to the spatial and textural possibilities introduced by reinforced concrete is itself a measure of change in the culture of building. The 1924 Empire Exhibition buildings and stadium at Wembley (Figure 1.2.22) was a major step in attaining the wider acceptance of exposed concrete as an architectural finish.

Oscar Faber described Wembley as "a milestone on the road toward the proper treatment of concrete" (as cited in Yeomans & Cottam 2001: 26). The architectural critic Lawrence Weaver (1876–1930) went further: "reinforced concrete has come into its own as a material used frankly and with vigorous invention for fine architecture" (as cited in Yeomans & Cottam 2001: 26). Wembley's architecture was even dubbed "the apotheosis of concrete"![13] But the very fact that it was being discussed represented a significant development.

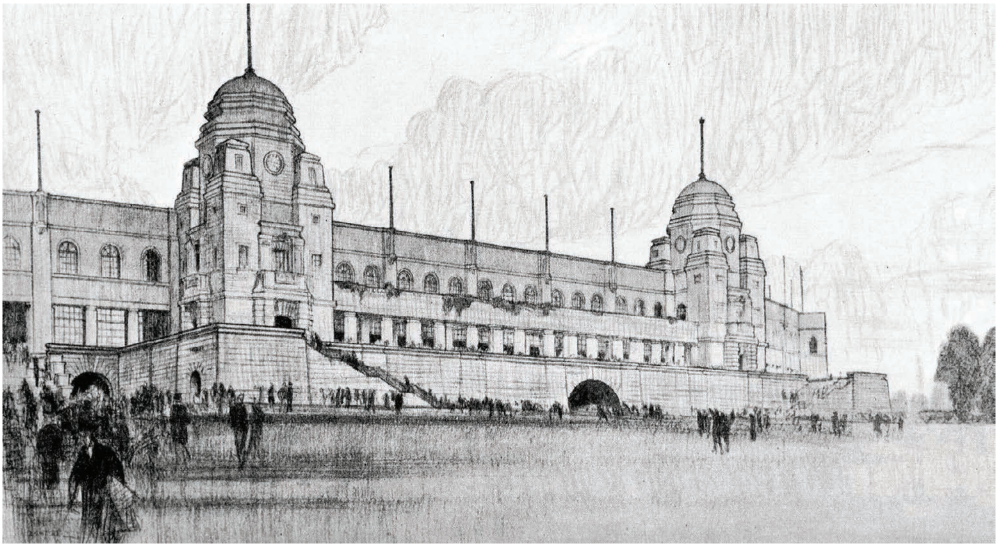


Figure 1.2.22 Architect's sketch of the Wembley Stadium, 1924.

Source: Concrete & Constructional Engineering 19 (4): 230.

> Whatever status reinforced concrete had enjoyed as an architectural material to date its extensive use in the Empire Exhibition meant that it had now arrived and, whatever faults there many have been in places, could hardly be ignored.
>
> (Yeomans & Cottam 2001: 28)

And so, the Exhibition led to a burst of interest in architectural circles: the *Architect's Journal* published a special issue in 1926, in which year Professor Arthur Beresford Pite (1861–1934) gave an important lecture on the subject of concrete that was clearly influenced by Wembley's success.

> Whilst concrete served so well the purposes of the Exhibition, yet the Exhibition has served an equally useful purpose for concrete. Here it has achieved a publicity which must surely eradicate any faint-hearted uncertainly and establish it as an accepted material. [. . .] The buildings of the Exhibition witness a new architectural stage in the history of reinforced concrete [. . .] [which] ultimately must develop an architecture of its own, in the same way as it has developed a branch of engineering.
>
> (Williams 1923: 423)

While overtly concrete architecture remained contentious in Britain, the momentum provided by the Empire Exhibition and renewed discussion at the RIBA led to the publication in 1927 of the first major monograph on the subject: Sir Thomas Penberthy Bennett (1887–1980) and Francis Rowland Yerbury's (1885–1970) *Architectural Design in Concrete*. In this, Bennett's thoughtful essay on concrete's influence on modern design introduced a superb photographic review of distinguished concrete buildings from around America and the Continent. The inclusion of so few British examples was, however, a reflection of how precarious concrete was in modern architectural thinking in the UK.

Collective Industry Representation

It was precisely to bolster the position of reinforced concrete that in 1932 a trade association was set up to promote technical research and commercial opportunity: the Reinforced Concrete Association (RCA).[14]

> The RCA has been formed to represent the interests of all who work in connection with reinforced concrete: to establish and uphold a standard of excellence in its design and construction, and – by making its unrivalled qualities more widely known to those who are responsible for the execution of modern structures – to maintain it in the leading position to which it has advanced among the materials of construction.

Membership embraces engineers, contractors and manufacturers of repute who work in reinforced concrete and desire by upholding a high standard of excellence, to maintain it in the leading position to which it has advanced among the materials of construction. Its objects were fourfold:

- to promote and develop the use of reinforced concrete, to bring it prominently before the public and to establish and maintain a public opinion favourable to it;
- to establish and uphold a standard of excellence in its design and construction, to collect and disseminate information relating to it, to originate improvements, to encourage and investigate inventions and to promote research;

- to serve as a channel of communication between the reinforced concrete industry and the Government and other public bodies, to arrange and promote the adoption of equitable forms of contract and assist by advice or otherwise persons engaged in the industry;
- to promote and improve the technical education of persons engaged in the reinforced concrete industry and to encourage the study of the arts and sciences associated with it.

As well as launching a promotional publication and maintaining a register of approved companies, its most urgent task was to help shape a nationally applicable Code of Practice.

The First Code of Practice

The London County Council's *Regulations relating to reinforced concrete and steel framed buildings* served their purpose during the 1920s, but by 1930s, the document was increasingly seen to warrant an update. In 1931, W.H. (later Sir William) Glanville (1900–1976), Chief Engineer at the Building Research Station of the Department for Scientific and Industrial Research, was consulted by the London County Council (LCC) on devising a Code of Practice linked to updated Regulations. He was appointed as Technical Officer to a Reinforced Concrete Structures Committee then being formed under the chairmanship of Sir George Humphreys. The membership of this committee was representative of relevant interests, and the RCA played a prominent part. Among the RCA's nominees was William Leslie Scott (1889–1950), Chief Engineer of member company Considere Constructions Ltd. Both Glanville and Scott served on a Sub-Committee entrusted with the task of drafting recommendations. The subsequent report, drawing heavily on Glanville's research at the Building Research Station (BRS), was published in 1933. Its recommendations were adopted by the LCC as the basis for new Regulations, and the report was widely accepted as the new Department of Scientific and Industrial Research (DSIR) Code of Practice.

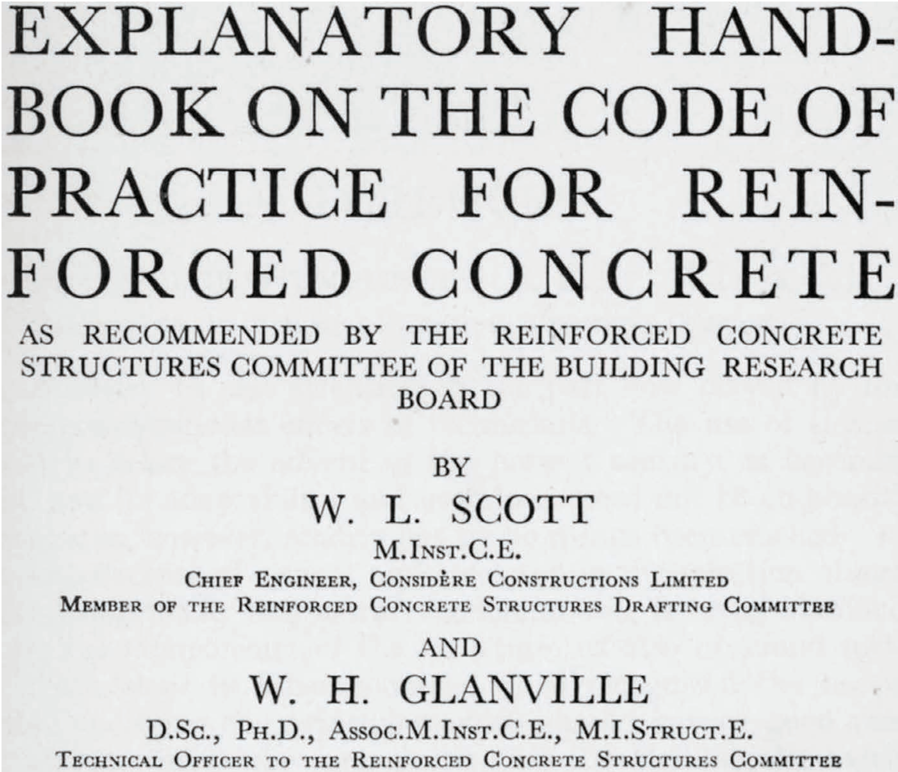
To guide prospective users of this Code, Glanville and Scott collaborated in writing an *Explanatory Handbook on the Code of Practice for Reinforced Concrete* (Figure 1.2.23), which was issued by Concrete Publications Ltd in 1934 to industry approval, as typified by this RCA statement:

> The Association is profoundly interested in all matters which may lead to increased efficiency in design and construction, and the new Code – in the drafting of which it has been privileged to take an active part – is a very great step forward in that direction. A wide knowledge and understanding of the Code among those who are responsible for the design of modern buildings must lead to economy, and we are glad to hear that Messrs. W.L. Scott and W.H. Glanville are carrying out this very useful work. The Code owes much to their labours, and their comments and explanations cannot fail to be of great service.
>
> (Scott & Glanville 1934: preface)

The *Handbook* became a standard work of which 16,000 copies were sold.

Concluding Comments

The story of reinforced concrete's introduction is one of fairly rapid adoption of a technology mostly developed abroad, in which Britain was attempting to catch up with French commercial success and German scientific study and standardization, almost despite the hostile regulatory



EXPLANATORY HAND-
BOOK ON THE CODE OF
PRACTICE FOR REIN-
FORCED CONCRETE

AS RECOMMENDED BY THE REINFORCED CONCRETE STRUCTURES COMMITTEE OF THE BUILDING RESEARCH BOARD

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TECHNICAL OFFICER TO THE REINFORCED CONCRETE STRUCTURES COMMITTEE

Figure 1.2.23 Explanatory Handbook on the Code of Practice for Reinforced Concrete, 1934.
Source: Concrete Society library.

environment. The initial impetus, or "push", was led by L.G. Mouchel and his subsequent competitors seeking to carve a commercial niche for their proprietary systems. What "pull" there was came from a small number of vocal architects and engineers wishing to exploit the potential of foreign ideas in the UK, in a market initially constrained by a supply side composed of patented systems and licensed contractors. Both faced the proscription of official building regulations. The task of enabling freedom of design in reinforced concrete was completed by 1915, but that of promoting and exploiting was not fully in place until the early 1930s. It is worth noting that the influential textbook by Charles Edward Reynolds (1900–1971), *Reinforced Concrete Designer's Handbook*, which was first published in 1932, is still in print today.

Notes

1 Grissel & Peto was a partnership between two cousins: the public works contractor Thomas Grissell (1801–1874) and Samuel Morton Peto (1809–1889).
2 *Concrete Quarterly* 10 (1951): 28.
3 Metropolitan Board of Works, Document 2431/1: Thames Embankment, Middlesex Side, contract no. 1, clause 45, 27 October 1863.
4 *Illustrated London News*, 6 July 1967: 26.
5 Contemporary newspaper reports, including *Maidstone Journal*, 13 July 1868; *Alloa Advertiser*, 15 October 1870; *Cardiff Times*, April 1876 and *Wiltshire & Gloucestershire Standard*, 9 January 1869.

6 *Cardiff Times*, April 1867.
7 "Scrivens Buildings, 1873" (Historic Concrete No. 34), *Concrete*, June 1977: 23.
8 Builder's Trade Circular, 12 August 1869 (Drake 1870: 3).
9 Anon. Mouchel-Hennebique Ferro-Concrete: List of Works Executed in the United Kingdom 1897–1919 (London: LG Mouchel & Partners, 1919) – annotated copy held in the Concrete Society library.
10 Obituary: "The Late Mr L.G. Mouchel", *Concrete & Constructional Engineering* 3 (1908): 180.
11 For a review of the early British literature of reinforced concrete, see Edwin Trout, 2013.
12 For more detail, see Anita Witten (2001).
13 Anon. "Concrete at Wembley", *Concrete and Constructional Engineering* 19 (4) (April 1924): 204.
14 For a history of the RCA, see Edwin Trout (2012).

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Chapter 1.3

The First Modern Concretes and the Rise of New Aesthetic Paradigms in 19th-Century France

Gilbert Richaud

Introduction

During the late modern period, and to use the term employed by the architectural historian Peter Collins (1959), early structural systems using concrete underwent an unprecedented development in France – in particular in the Lyon region. In fact, these new processes led to the development of a completely new material. Known as *pisé* or *béton de terre* (rammed earth concrete), *béton de mâchefer* (clinker concrete) or *béton de gravier* (gravel concrete), these masonries were created by manually compacting the different materials (earth, mortar, gravel) within removable timberwork, without wooden or metal reinforcements. With these procedures, moulded walls could be erected on the site where the materials came from. The revival of the vernacular technique of rammed earth construction and an interest in lithogenesis in academic circles rapidly combined with the interest of other scholars looking to revive one form of the ancient *structura caementicia*: the *emplekton*. From the 18th century onwards, this formed the basis for the use of a new type of masonry obtained from small elements such as shards, ragged stones or brick fragments known as *blocaille*. The discoveries of the engineer Louis-Joseph Vicat (1786–1861) related to the composition of limes and cements which enabled their controlled manufacture led to the regular and standardized production of high-strength mortars and, in turn, their first practical applications in architecture in the Tarn-et-Garonne region in 1830. But we owe the demonstration of the first architectural applications of the new system to the engineer and manufacturer François Coignet (1814–1888), a system he called *béton aggloméré* (agglomerate concrete, also known as Coignet concrete). Coignet devoted himself to exemplifying the potential large-scale uses of this system for the construction of important buildings, residences or even aqueducts. Meanwhile, the neo-vernacular procedure of *pisé de mâchefer* (a rammed composition of lime, blast furnace slag or coal ashes or solid waste from steam engines, which we will refer to here as clinker concrete) was widely used in the Lyon region by the architects Gaspard André (1840–1896) and Tony Garnier (1869–1948). Their aesthetic approaches to these techniques are proof of a paradigm shift which undoubtedly stemmed from the unprecedented importance given by Eugène Viollet-le-Duc (1814–1879) and his successors to monolithic masonry in the myths of the origins of architecture, of which these modern techniques would provide a distant echo.

This chapter briefly traces the history of the creation of these unconventional masonries in France in the modern period and, in particular, their development in the early 19th century following the publication of *Traité théorique et pratique de l'art de bâtir* by Jean Rondelet (1743–1829). The aim is also to highlight how these innovations continued up to the 1920s, particularly for new decorative and aesthetic strategies used both in architecture and urban design.

DOI: 10.1201/9781003368656-5

Origins and Development of a Modern Moulded Masonry

Lyon-born architect and technician Jean-Baptiste Rondelet (1743–1829) was a pupil and collaborator of Jacques-Germain Soufflot (1713–1780), the architect in charge of the construction of the Church of Sainte-Geneviève (now the Panthéon) in Paris for several years. The second part of the first volume of his *Traité théorique et pratique de l'art de bâtir* (published in 1803) perfectly evokes the expectations concerning the creation and production of new construction materials at the beginning of the industrial era. This text is in fact entirely devoted to the "compositions and [. . .] preparation that art has come up with to replace the use of stones" (Rondelet 1802: viii). Until 1855, one of the 17 editions of this treatise grouped the knowledge gathered on this subject under the title "Pierre artificielle" ("Artificial Stone").[1] In this section, Rondelet first devoted 12 pages and two engraved plates to an article entitled *Du pisé* (Rondelet 1802: I, 2: 228–247), presenting to a specialized public a vernacular technique, quite widespread in the south-east of France, which had undergone a revival in the mid-18th century (Figure 1.3.1).

This technique had been illustrated (Figure 1.3.2) for the first time in 1765 by the naturalist Jean-Louis Alléon-Dulac (1723–1768), before François Cointeraux (1740–1830, master-builder, architect and inventor from Lyon, as well as self-proclaimed professor of rural architecture) propagated it at the end of the 18th century.[2]

The translation into eight languages of Cointeraux's four *Cahiers de l'Ecole d'architecture rurale*, published in Paris from 1790 to 1791, contributed to the international diffusion of this

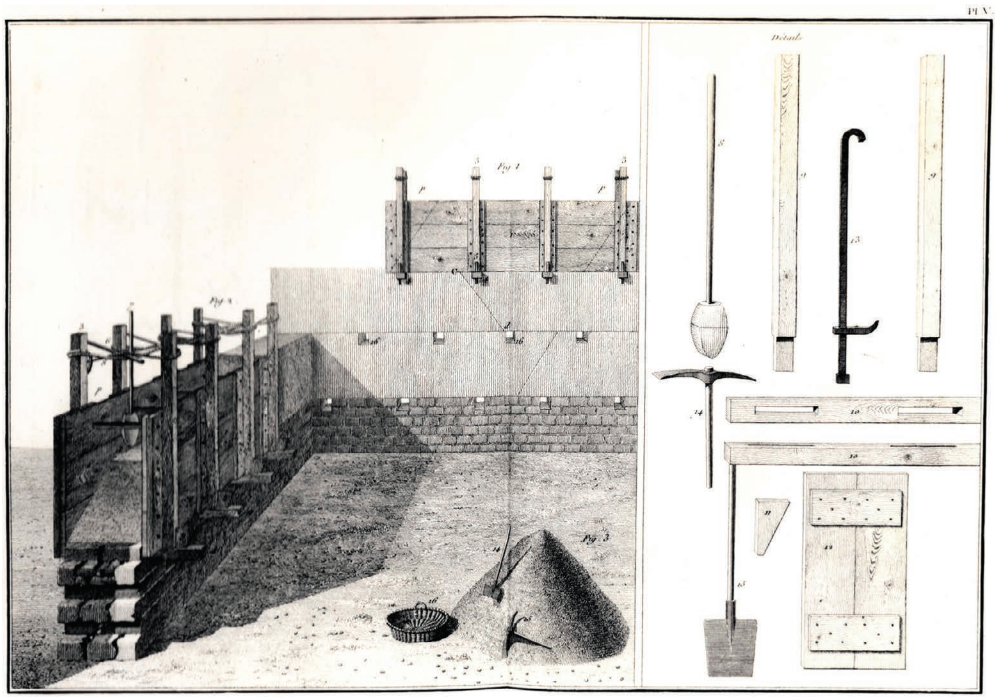


Figure 1.3.1 J.-B. Rondelet, view of a wall and implements for the construction of *pisé* (Rondelet 1803).

Source: Bibliothèque municipale de Lyon. Photo credit: D. Nicole.

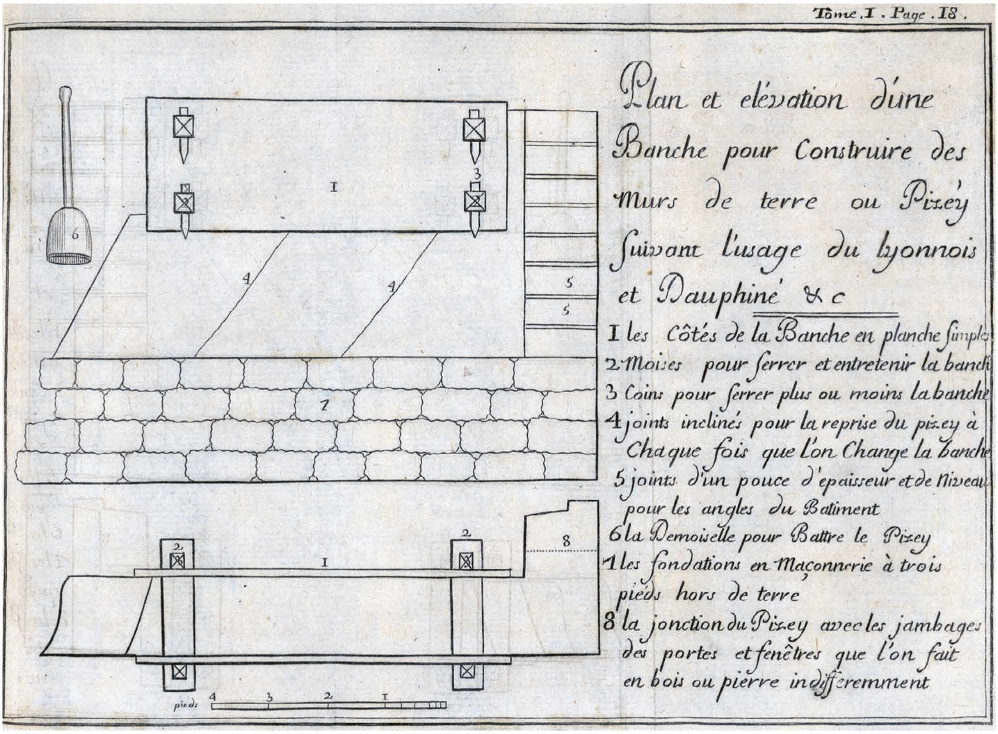


Figure 1.3.2 “Plan et élévation d'une banche pour construire des murs de terre en Pizey suivant l'usage du lyonnais et Dauphiné (Horizontal and vertical views of a formwork pannel set for earthwork as used in the Lyon region and in the Dauphiné province)” (Alléon-Dulac 1765).

Source: Bibliothèque municipale de Lyon. Photo credit: D. Nicole.

technique. Cointeraux had also proposed extending the field of application of this material to the production of compressed earth blocks (Figure 1.3.3).

This *nouveau pisé par appareil* (rammed earth made of blocks) would allow the construction of floors and vaults which, combined with load-bearing walls made of the same material, would transform each of the small buildings he proposed in his engravings into a sort of fireproof monolith of which a prototype still exists near Paris, in the park of Château Malmaison.[3] At the same time, the official portrait of David Gilly (1748–1808), architect to King Frederic II of Prussia, who is shown accompanied by the tools used for *pisé* and *nouveau pisé* (Figure 1.3.4) – and the foundation of a school of architecture made of rammed earth at Tiukhili near Moscow under the patronage of Tsar Nicolas II – are testament to the hopes at the end of the Age of Enlightenment of creating an abundant, economical, universal building material, mainly intended for the dwellings of peasants in Europe, serfs in Russia and plantation slaves in the USA (Cellauro & Richaud 2005).

In his work, Rondelet also proposed a parallel between *pisé de terre* (rammed earth) and the “[ancient] masonry made with an infill of rough stone or cut stone blocks” (Rondelet 1802: I, 2, 340). He states: “The masonry of these walls seems to have been made (as we have already said), fitting into a sort of slip mould made of planks, more or less like those used for pisé” (Rondelet

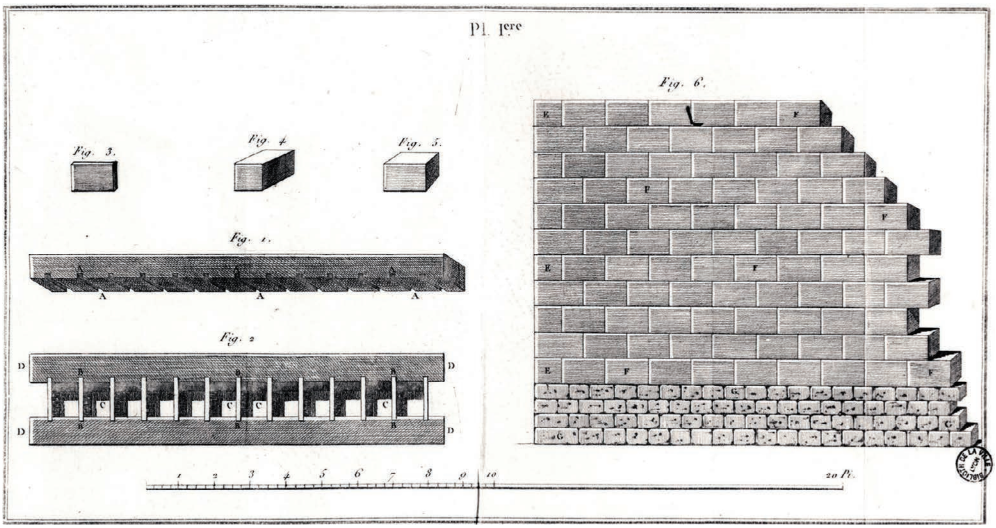


Figure 1.3.3 F. Cointeraux, the *nouveau pisé par appareil* (Cointeraux 1791: pl.1).
Source: Bibliothèque municipale de Lyon. Photo credit: D. Nicole.

Figure 1.3.4 W. Chodowiecki, engraved portrait of David Gilly, 1796.
Source: Berlin, Staatliche Museen, Kupfestichkabinett. Photo credit: Kupfestichkabinett, Berlin.

1802: I, 2, 340). The connection between the ancient *emplekton* and the vernacular tradition of the structural system of moulded masonries is not new, dating back to the early modern period in Italy. During the Renaissance period, Fra Giocondo (*ca*. 1433–*ca*. 1515) and Cesare Cesariano (*ca*. 1475–1543) had given famous illustrations of the *opus signinum* described by Vitruvius for the construction of cisterns (Vitruvius: 8.7, 14–15; Fra Giocondo 1511: f° 83 r°; Cesariano 1521: f° CXXXXI v.). While according to these authors, the *emplekton* (or the sixth of the seven types of walls (*Structuram genera*) described by Vitruvius) consisted of filling the gap between two stone walls with a mixture of mortar and pebbles (Vitruvius 2.8–7) (Figure 1.3.5), in his *Quattro libri* Palladio reinterpreted this type of masonry for the first time (Figure 1.3.6), calling it *maniera riempiuta* (infilling method), by means of a completely new system of mobile wooden formwork (Palladio 1570: 13; Cellauro & Richaud 2020).

Palladio was inspired by Pliny the Elder's description of the wooden formwork used in Africa and Spain for the construction of earthen walls in the time of Hannibal (Pliny the Elder:

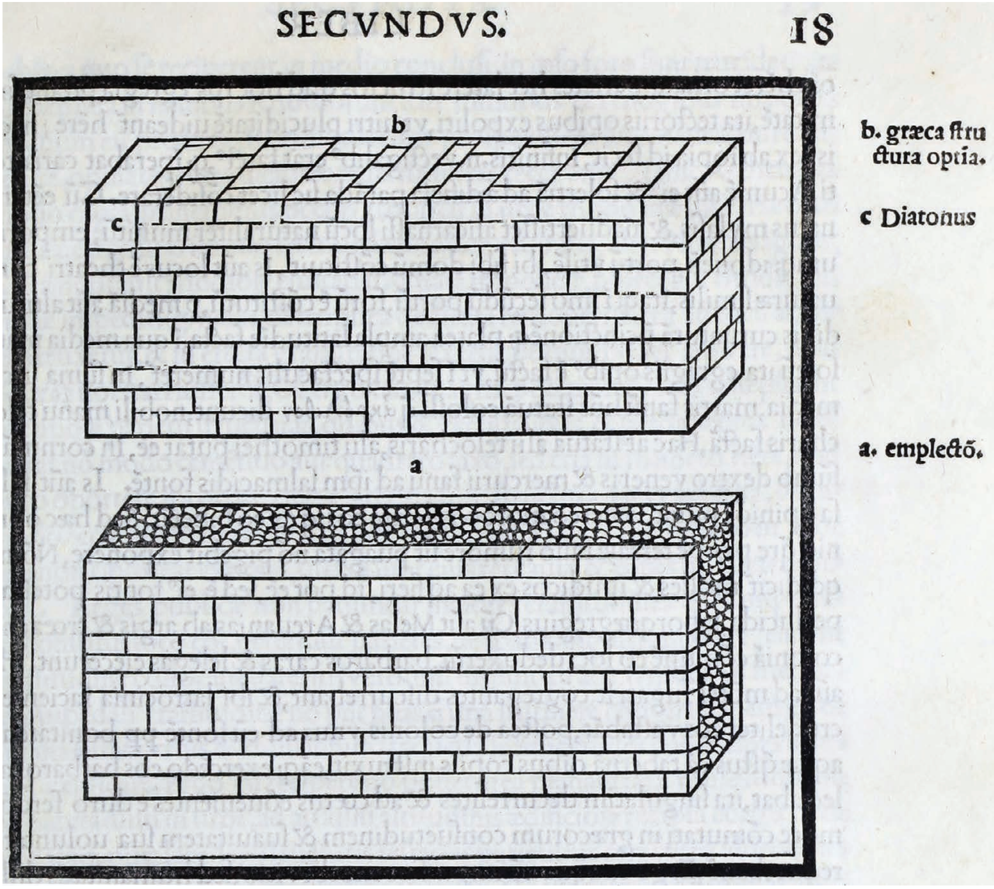


Figure 1.3.5 Fra Giocondo – an antique type of masonry after Vitruvius: the Emplekton (Fra Giocondo 1511: fol. 82v).

Source: The Getty Research Institute, Los Angeles, 85-B6155. Photo credit: The Getty Research Institute, Los Angeles.

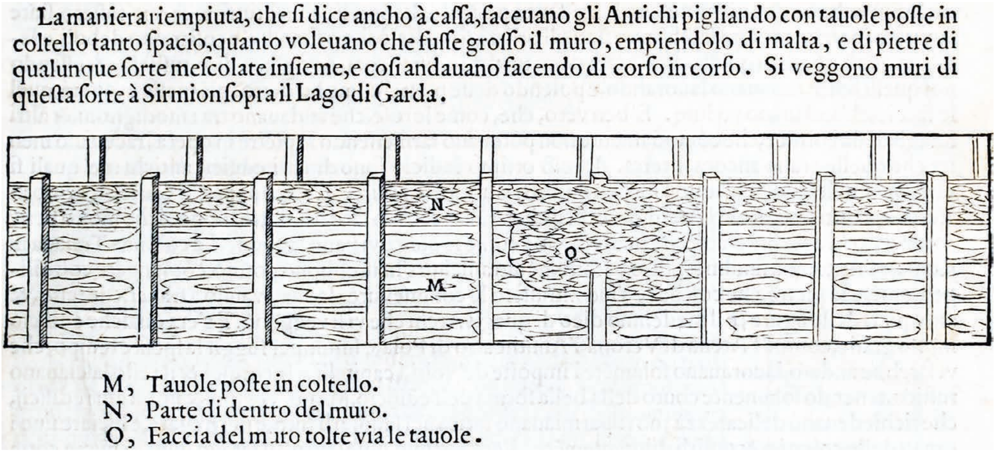


Figure 1.3.6 A. Palladio – an antique type of masonry: *La maniera riempiuta che si dice ancho a cassà* (Palladio 1570: 13, detail).

Source: The Getty Research Institute, Los Angeles, 86-B23467. Photo credit: The Getty Research Institute, Los Angeles.

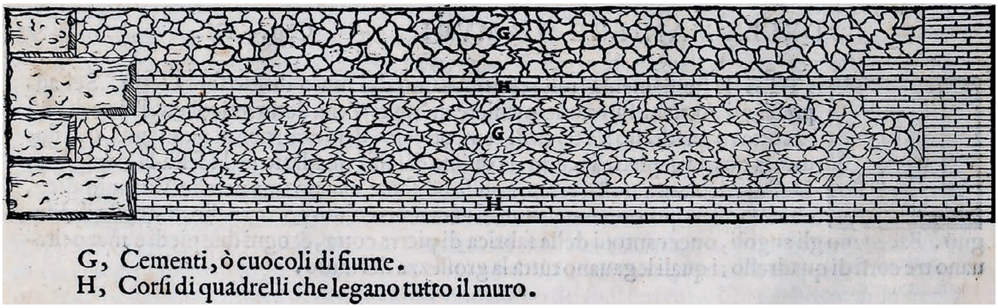


Figure 1.3.7 A. Palladio – an antique type of masonry: *Muri di cementi, ò cuocoli di fiume* (Palladio 1570: 12, detail).

Source: The Getty Research Institute, Los Angeles, 86-B23467. Photo credit: The Getty Research Institute, Los Angeles.

§ 35.48.1). This technique had been mentioned by Alberti (1404–1472) in his *De Re Aedificatoria* (1485: III, 8) but most notably by Daniele Barbaro (1514–1570) in his editions of Vitruvius's treatise, for which Palladio had provided illustrations (Barbaro 1556, 1567; Williams 2019). Palladio was also inspired by an ancient concrete wall he had discovered in the ruins of the Villa de Catulle (late to first century BC) in Sirmione, near Lake Garda, Italy. In addition to the aforementioned *maniera riempiuta*, Palladio also refers to another method of walling, probably in formwork, the *muri di cementi* or walls of cement (Figure 1.3.7) made from "pietre roze di montagna" ("rough stones") or "cuocoli di fiume" ("river pebbles"), of which he cites ancient examples such as the walls of Turin and those of the amphitheatre in Verona (Palladio 1570: 12).

The methods described by the Vicenza architect were disseminated in France in the mid-17th century by Roland Fréart de Chambray (1606–1676), who translated "de remplage" as *maniera*

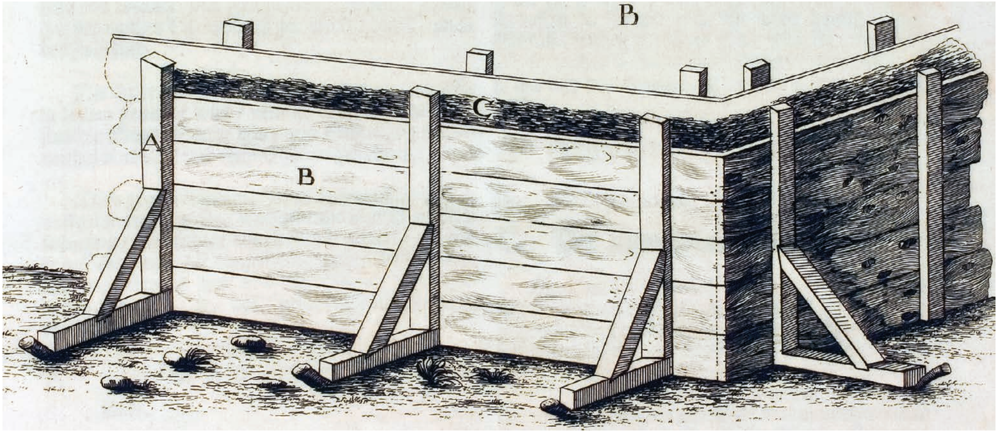


Figure 1.3.8 Infill wall based on Palladio's *maniera riempiuta* (Dieussart 1697: pl. II, detail).

Source: Heidelberg University Library, Heidelberg, T 2106 RES. Photo credit: Heidelberg University Library.

riempiuta (Fréart de Chambray 1650: 11). Claude Perrault (1613–1688) ignored Palladio's interpretations of masonry in his important translation of Vitruvius in 1673. However, the French-born Huguenot architect Charles Philippe Dieussart (1625–1696) includes them in his *Theatrum architeturae civilis* published in 1679 (Figure 1.3.8). In particular, he uses the wooden formwork to represent the construction of an earthen wall which, according to him, was used by the peasants "in the region of Milan, on the shores of Lake Garda, as in Champagne, France".[4]

In the 18th century, the architect Jacques Raymond Lucotte (*ca*. 1733–1804) combined Palladio's illustrations with his presentation of ancient masonry in the article "Maçonnerie" in Diderot and d'Alembert's *Encyclopédie* in 1765. The *emplekton* is termed "limousinage", and the "murs de remplage" ("infill walls") are shown (Figure 1.3.9) with their wooden formwork (Lucotte 1765). Pierre Patte (1723–1814), in his supplement to the *Cours d'architecture* by Jacques François Blondel (1618–1686), refers exclusively to Palladio and, in particular, to the "wooden boxes" of the sixth type "which were filled with all kinds of stones or rubble, in a bath of mortar" (Blondel 1777: 257, pls LXVIII, LXIX). In the last quarter of the century, Antoine-Joseph Loriot (1716–1782) mentions the construction of Roman aqueducts using wooden formworks in connection with new mortars of his invention (Loriot 1774: 10).

Polycarpe de La Faye, a high ranking official, imagined artificial stones made using the same process, which he borrowed from the vernacular technique of the *pisé de terre* (La Faye 1777: V, 59 note i; 1778: VII, 12–15, 37 note u; 79 note y).[5] And having given the architect Georges-Claude Goiffon (1713–1776), author of *L'art du maçon piseur* (1772), the opportunity to publish the first complete article entirely devoted to rammed earth in his *Journal de Physique*, Abbé François Rozier (1734–1793), an agronomist from Lyon, went on to reference another technique close to *opus signinum* in the article "Béton" published in the second volume of his *Cours Complet d'Agriculture* in 1785 (Rozier 1785: II, 244–246).[6] Rozier also argued that *béton* (concrete) was a "very economical and underused" type of masonry, pointing to its application in the construction of vaulted "bléton" basements in rural houses around Lyon, which took two years to build. The *béton* technique also had a local vernacular origin, as it appears as early as the 13th century in the consular archives of the city of Lyon in connection with the foundations of a bridge (Guillerme 1995: 156). This material seemed familiar to the *maîtres fontainiers* (master fountain builders) of

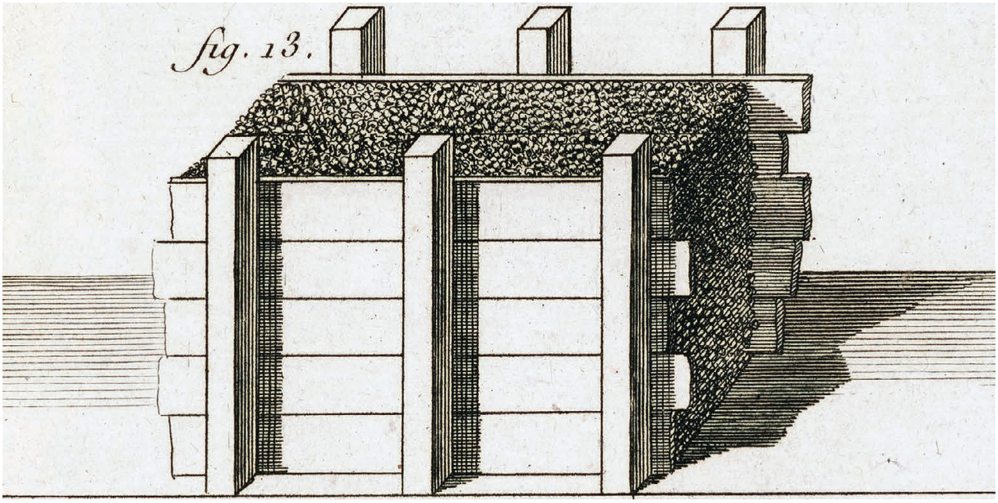


Figure 1.3.9 Infill wall based on Palladio's *maniera riempiuta* (Lucotte 1765: 9, pl. II, detail).

Source: The Getty Research Institute, Los Angeles, 84-B31186. Photo credit: The Getty Research Institute, Los Angeles.

Lyon in the 17th century. It is reminiscent of natural concretions, that is "naturefacts", as indicated by the use of the word *béton* in place names the upper Rhône valley (Guillerme 1995). In 1761, in *L'Art du chaufournier*, the science scholar Charles-René Fourcroy de Ramecourt (1715–1791) evoked the work of the *chaufourniers* or lime-kiln makers who worked on the banks of the Rhône and the Saône, whose "lime hardens quickly; and when mixed with the gravel of the Rhône, it forms a very hard mass, which is called *Béton*" (Fourcroy de Ramecourt 1761: 51). In 1767, it was undoubtedly the engineer of the bridges and roads of the Burgundy region who anonymously communicated to the Marquis de Marigny (1727–1781), Director General of the King's buildings, a *Mémoire sur la manière de mouler les ponts en mortier de béton*.[7] In that memorandum, he stated that his observation of the behaviour of a 9-m-long concrete "platte bande" ("platform") after the demolition of an old fortification wall in Bourg-en-Bresse (Figure 1.3.10) had led him to build several concrete "pontceaux" ("small bridges") in this region in a very economical way.

At the beginning of the 19th century, Rondelet produced an initial summary of these different traditions (Figure 1.3.11): the scholarly tradition of the *emplekton*; the vernacular tradition of the recently updated rammed earth construction and, finally, the concrete technique, which was still little used.[8]

He points out the characteristics of this formwork masonry, which "stripped of its facings seems to form a single mass" and at the same time underlines the aspirations of his time for:

> this simple building method, which [in antiquity] had made it possible to employ thousands of workers at a time, and which lent itself to the execution of all kinds of forms, making possible what would have been insurmountably difficult by other means. Circular forms and vaults, in ashlar constructions and even in wood, require particular knowledge, extraordinary work, selected materials or materials of considerable volume, difficult to transport and place, causing much waste, time and expense, while that of small stones becomes ordinary work requiring only a little care.
>
> (Rondelet 1802: I, 2, 342)

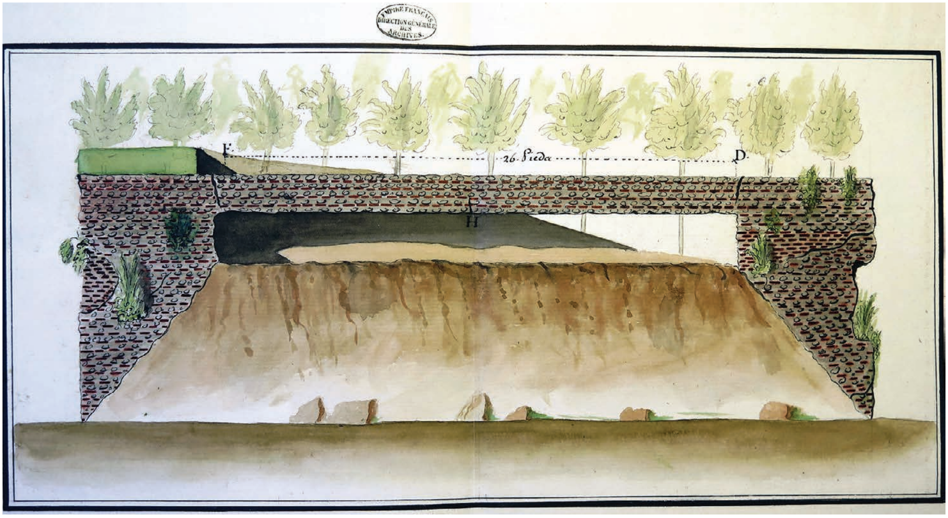


Figure 1.3.10 Anonymous, drawing of a 9-m lintel formed after the demolition of an ancient city wall in Bourg-en Bresse (France) in *Mémoire sur la manière de mouler les ponts en mortier de béton*.

Source: Archives Nationales, ms. ANF, O1 1294–182. Photo credit: the author.

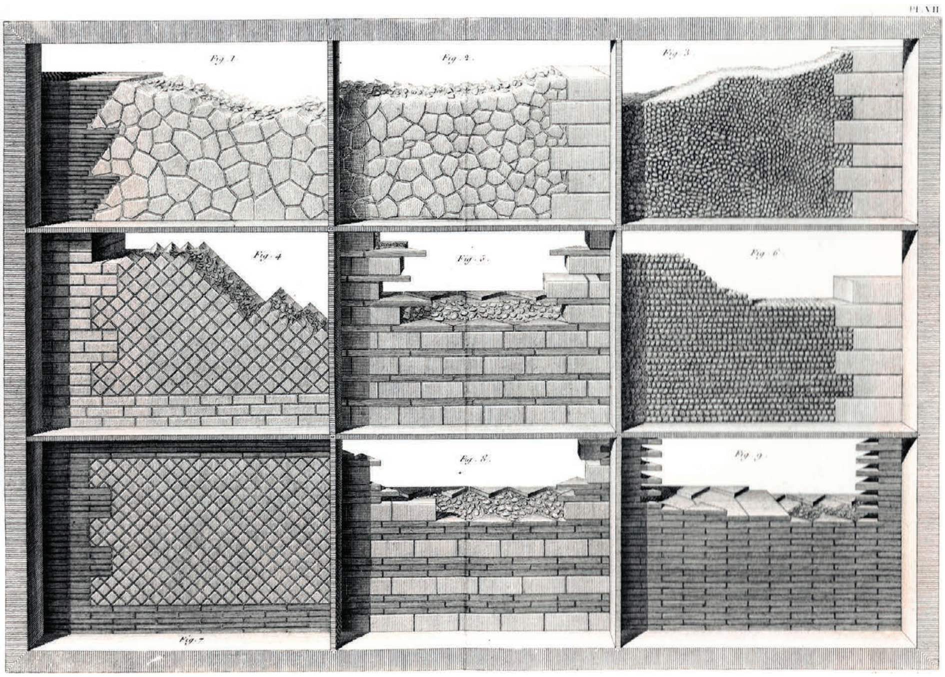


Figure 1.3.11 Ancient and modern infill walls (Rondelet 1803: pl. VII).

Source: Bibliothèque municipale de Lyon. Photo credit: D. Nicole.

He added: "Walls could thus be built using all kinds of rubble and small stones, making use of movable encasements almost like those used for *pisé*" (Rondelet 1802: 341). By pointing out the interrelationships between these different traditions, Rondelet indirectly formulated some questions concerning the use of these processes at the dawn of the industrial revolution. In particular, he showed how a new technical culture was growing up around these alternative materials on the basis of a particular set of ideas and knowledge. From then on, it was a question of these new cultures reaching the field of architecture, following the example of Roman monuments, but also of serving a new programme such as that of the "poor man's hut", as Cointeraux tried to do with rammed earth under the Revolution and the Empire. This idea would remain essentially unchanged in these processes until the end of the modern era. The thought of a new material – indeed, a new materiality, in the sense defined by Antoine Picon – was thus gradually set in motion (Picon 2018).

This notwithstanding, for some 20 years, the technical literature was initially limited to illustrating the so-called *blocaille* masonry, that is masonry made of small agglomerated elements compressed in formworks, similar to Palladio's "muri di cementi" (Rondelet 1802: I, 2, 346–347). In 1820, Quatremère de Quincy (1755–1849) pointed out that the very term *maçonnerie* (masonry) had changed its meaning. For him, it was in fact a "way of building using materials that are not very large, not very expensive, easier to transport and handle and more economical than cut stone" (Quatremère de Quincy 1820: II, 647). However, experiments and achievements remained modest. Claude Fleuret (1744–1817), professor of architecture at the Royal Military Schools of Sorèze, Pont à Mousson and later Paris, tried out La Faye's methods in 1777 to experiment with new mortars (La Faye 1778: xx). He wrote: "One observed, with a kind of astonishment, a paste-like composition, workable in a manner very similar to plaster mortar, which quickly became firm, solidified on sight and acquired the hardness of stone in twenty-four hours" (Anonymous 1824). In 1802, in his workshop in Nancy, he had built with the help of these processes "large basins, wine tanks, paving stones in rooms used intensively, on the ground floor of houses, on pavements, terraces and mosaic floors, troughs of all sizes for the use of factories [. . .] as well as cisterns in places where water is scarce" (Fleuret 1807). In his workshop (Figure 1.3.12), he had also built "a supporting wall crowned by a slab of the same material [. . .] and which has the appearance of cut stone, without joints, in a length of 16 metres" (Fleuret 1807).

He published his findings in 1807 in *L'Art de composer les pierres factices aussi dures que le caillou* (Fleuret 1807). The following year, Cointeraux introduced the term *béton* (concrete) for the first time in the title of his work *Le béton préférable aux pierres factices de pur mortier*, where, in response to Fleuret's work, he described the use of this material in his native region and presented a project for an egg-shaped cistern (Figure 1.3.13), showing that the technique was still limited to *ouvrages aquatiques* (hydraulic works) and buried structures.

It was not until the discoveries of the engineer Louis-Joseph Vicat, from 1818 onwards, that precise scientific measurements were established for the controlled manufacture of mortars whose resistance was multiplied by a factor of 12 within 15 years. In the 1830s, the Castres architect François Martin Lebrun (1799–1849) built the walls and vaults of his brother's house in Marssac and those of the church of Corbarieu in the department of Tarn-et-Garonne, combining the structural process of rammed earth with a concrete developed thanks to Vicat's discoveries. In 1835, he dedicated his first manual, *Méthode pratique pour l'emploi du béton en remplacement de toute autre espèce de maçonneries dans les constructions en général*, to Vicat (Lebrun 1835). In that manual, Cointeraux's procedures are cited once more. Lebrun[9] again paid homage to Vicat in 1843 (Figure 1.3.14) in his most important work, *Traité pratique de l'art de bâtir en béton* (Lebrun 1843).

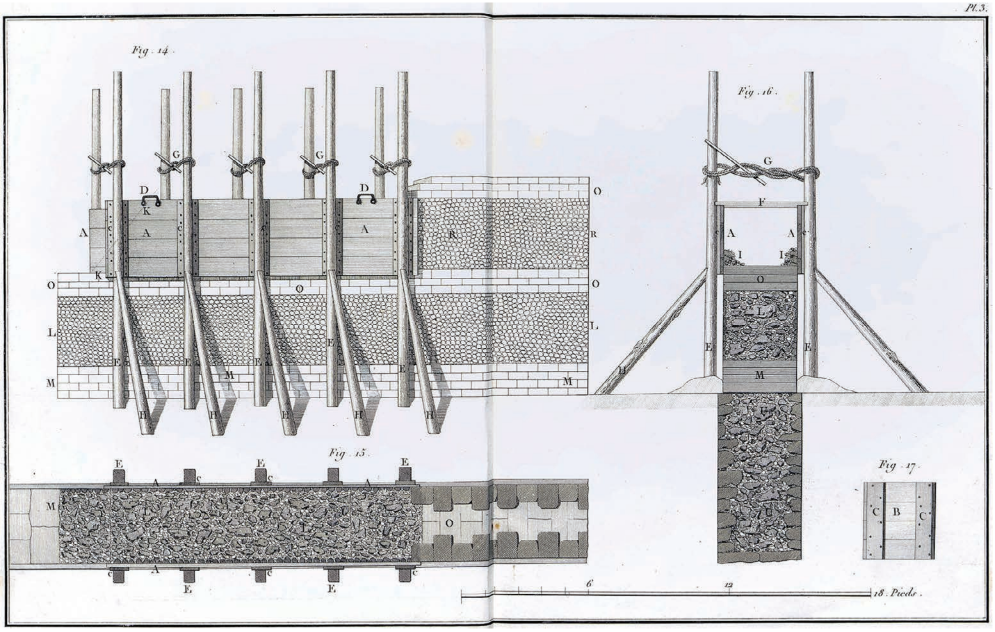


Figure 1.3.12 Plan, elevation and cross-section of concrete pebble masonry with removable wooden formwork (Fleuret 1807: pl. 3).

Source: École Nationale des Ponts et chaussée, Marne-la-Vallée. Photo credit: G. Saquet.

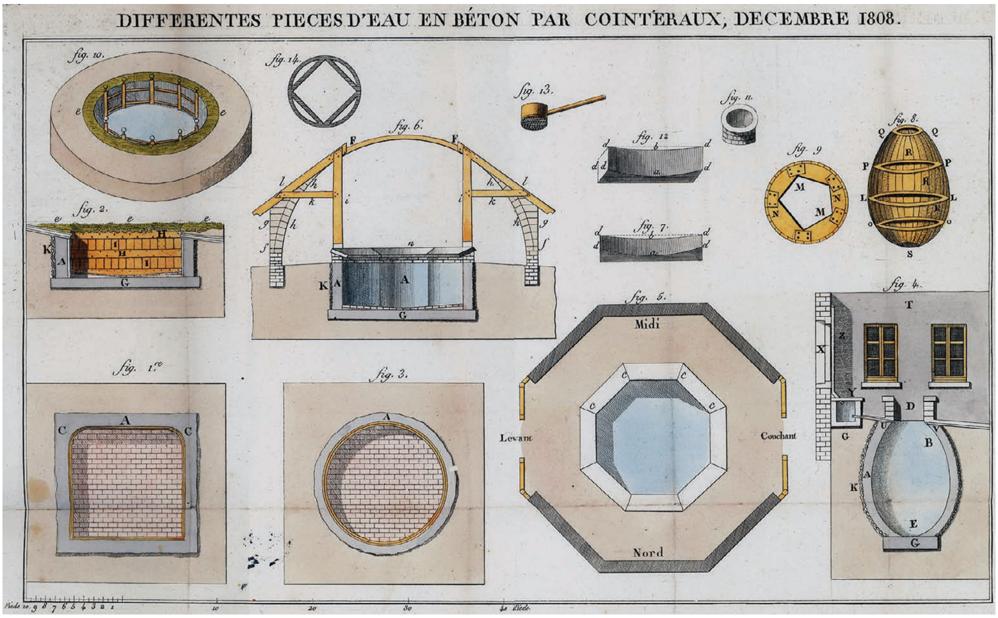
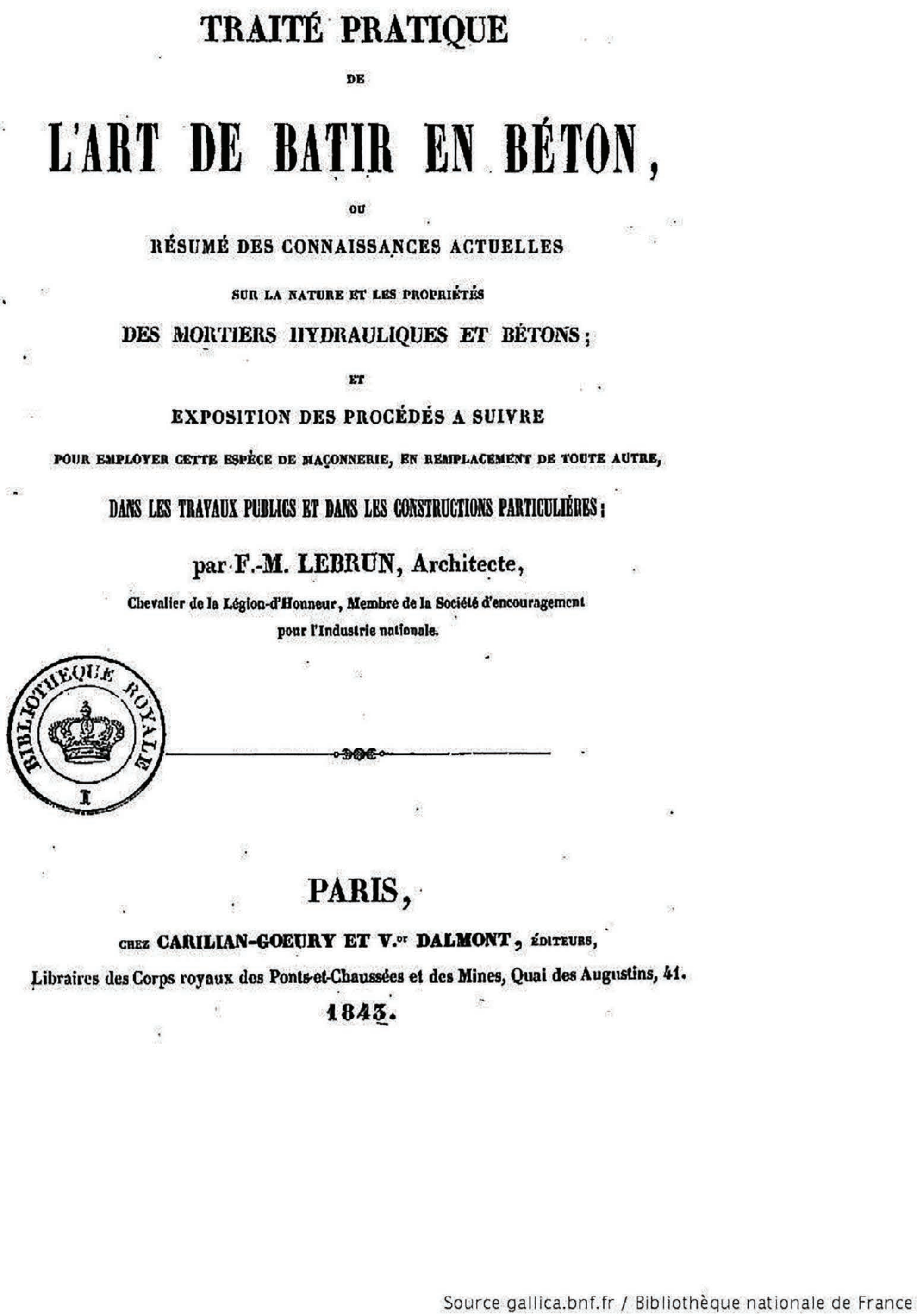


Figure 1.3.13 "Différentes pièces d'eau en béton" (Cointeraux 1808).

Photo credit: J.-P. Garric.


TRAITÉ PRATIQUE

DE

L'ART DE BATIR EN BÉTON,

OU

RÉSUMÉ DES CONNAISSANCES ACTUELLES

SUR LA NATURE ET LES PROPRIÉTÉS

DES MORTIERS HYDRAULIQUES ET BÉTONS;

ET

EXPOSITION DES PROCÉDÉS A SUIVRE

POUR EMPLOYER CETTE ESPÈCE DE MAÇONNERIE, EN REMPLACEMENT DE TOUTE AUTRE,

DANS LES TRAVAUX PUBLICS ET DANS LES CONSTRUCTIONS PARTICULIÈRES;

par F.-M. LEBRUN, Architecte,

Chevalier de la Légion-d'Honneur, Membre de la Société d'encouragement pour l'Industrie nationale.

PARIS,

CHEZ CARILIAN-GOEURY ET V.^{or} DALMONT, ÉDITEURS,

Libraires des Corps royaux des Ponts-et-Chaussées et des Mines, Quai des Augustins, 41.

1843.

Figure 1.3.14 Title page of *Traité pratique de l'art de bâtir en béto*n (Lebrun 1843).

Source: Gallica photo.

François Coignet (1814–1883), an engineer and manufacturer of Lyon origin, was probably responsible for the most extensive experiments on monolithic moulded walls and artificial stone in the mid-19th century (Richaud 2015, 2022). Trained as a chemist, Coignet used the *pisé de mâchefer* technique inherited from the earth-ramming technique for the construction of a factory in Lyon in 1848. In this neo-vernacular technique, earth was replaced with a mixture of lime and solid waste from the smelting of iron ores and the burning of coal in blast furnaces and steam engines. In 1853, Coignet developed this technique in Saint-Denis, in the Paris region, by building a house on the banks of the Seine whose "foundations, cellar vaults, [. . .] all the walls without exception are of béton-pisé, as are the cornice, mouldings, cordons, entablatures, balustrades, supporting walls, the whole forming a monolith" (Degousée 1855). In fact, the term *béton-pisé* was used here to designate the *pisé de mâchefer* used for the main walls, as well as more elaborate mortars moulded *in situ* to form the decorative *modénatures*. During the construction of the buildings of his chemical factory in 1854 (Figure 1.3.15), Coignet, seeking to use "materials other than ash", carried out numerous tests which he published on the occasion of the *Exposition Universelle* of 1855 (Coignet 1855). He first used these new mixtures for the construction of small experimental buildings, such as the Suresne stationmaster's house for the engineer Eugène Flachat, which was "a monolith from the crest to the base", as was a small building built later at the Saint-Denis site.

For the construction of the guard house in the Bois de Vincennes (Figure 1.3.16), Coignet tells us that he used "too many moulds". At the end of the 1850s, he built more, similarly complex structures in Paris, such as the chicken coop in the Jardin d'Acclimatation, the retaining wall of the Passy cemetery and the so-called Emperor's staircase in the Trocadéro district.

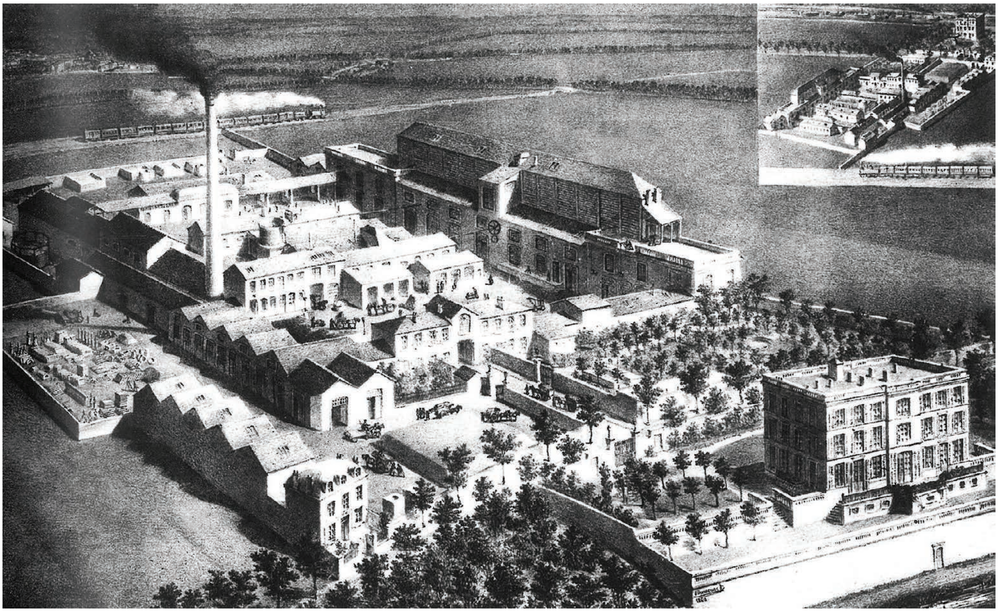
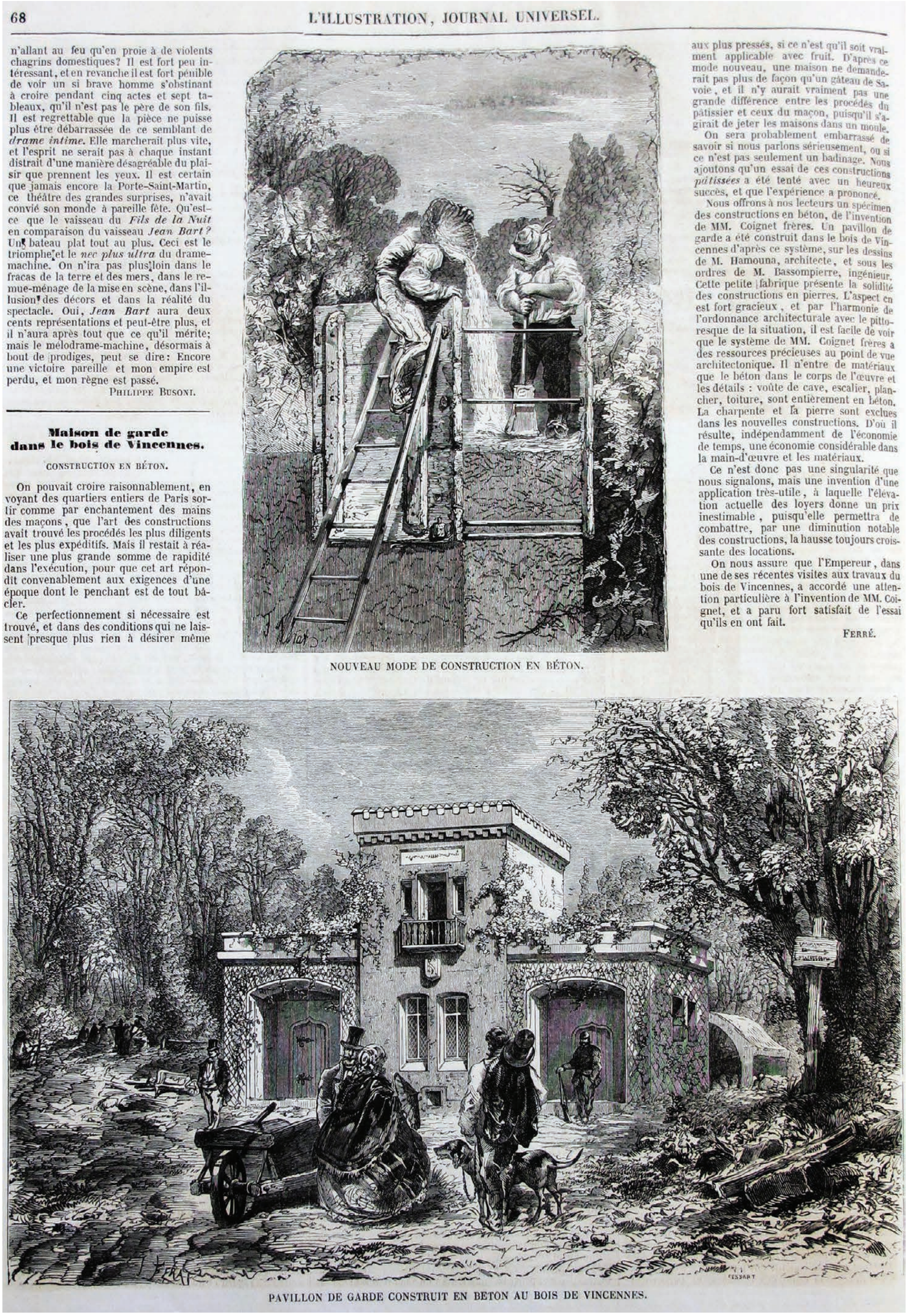


Figure 1.3.15 J.-H. Devicque, bird's-eye view from the north-east direction of the F. Coignet's dwelling houses and Société Coignet père et fils's chemical factory at Saint-Denis, lithography, 1862.

Source: Bibliothèque nationale de France.



68 L'ILLUSTRATION, JOURNAL UNIVERSEL.

n'allant au feu qu'en proie à de violents chagrins domestiques? Il est fort peu intéressant, et en revanche il est fort pénible de voir un si brave homme s'obstinant à croire pendant cinq actes et sept tableaux, qu'il n'est pas le père de son fils. Il est regrettable que la pièce ne puisse plus être débarrassée de ce semblant de *drame intime*. Elle marcherait plus vite, et l'esprit ne serait pas à chaque instant distrait d'une manière désagréable du plaisir que prennent les yeux. Il est certain que jamais encore la Porte-Saint-Martin, ce théâtre des grandes surprises, n'avait convié son monde à pareille fête. Qu'est-ce que le vaisseau du *Fils de la Nuit* en comparaison du vaisseau *Jean Bart?* Un bateau plat tout au plus. Ceci est le triomphe et le *nec plus ultra* du drame-machine. On n'ira pas plus loin dans le fracas de la terre et des mers, dans le remue-ménage de la mise en scène, dans l'illusion des décors et dans la réalité du spectacle. Oui, *Jean Bart* aura deux cents représentations et peut-être plus, et il n'aura après tout que ce qu'il mérite; mais le mélodrame-machine, désormais à bout de prodiges, peut se dire: Encore une victoire pareille et mon empire est perdu, et mon règne est passé.

PHILIPPE BUSONI.

Maison de garde dans le bois de Vincennes.

CONSTRUCTION EN BÉTON.

On pouvait croire raisonnablement, en voyant des quartiers entiers de Paris sortir comme par enchantement des mains des maçons, que l'art des constructions avait trouvé les procédés les plus diligents et les plus expéditifs. Mais il restait à réaliser une plus grande somme de rapidité dans l'exécution, pour que cet art répondît convenablement aux exigences d'une époque dont le penchant est de tout bâcler.

Ce perfectionnement si nécessaire est trouvé, et dans des conditions qui ne laissent presque plus rien à désirer même aux plus pressés, si ce n'est qu'il soit vraiment applicable avec fruit. D'après ce mode nouveau, une maison ne demanderait pas plus de façon qu'un gâteau de Savoie, et il n'y aurait vraiment pas une grande différence entre les procédés du pâtissier et ceux du maçon, puisqu'il s'agirait de jeter les maisons dans un moule.

On sera probablement embarrassé de savoir si nous parlons sérieusement, ou si ce n'est pas seulement un badinage. Nous ajoutons qu'un essai de ces constructions *pâtissées* a été tenté avec un heureux succès, et que l'expérience a prononcé.

Nous offrons à nos lecteurs un spécimen des constructions en béton, de l'invention de MM. Coignet frères. Un pavillon de garde a été construit dans le bois de Vincennes d'après ce système, sur les dessins de M. Hamouna, architecte, et sous les ordres de M. Bassompierre, ingénieur. Cette petite fabrique présente la solidité des constructions en pierres. L'aspect en est fort gracieux, et par l'harmonie de l'ordonnance architecturale avec le pittoresque de la situation, il est facile de voir que le système de MM. Coignet frères a des ressources précieuses au point de vue architectonique. Il n'entre de matériaux que le béton dans le corps de l'œuvre et les détails : voûte de cave, escalier, plancher, toiture, sont entièrement en béton. La charpente et la pierre sont exclues dans les nouvelles constructions. D'où il résulte, indépendamment de l'économie de temps, une économie considérable dans la main-d'œuvre et les matériaux.

Ce n'est donc pas une singularité que nous signalons, mais une invention d'une application très-utile, à laquelle l'élévation actuelle des loyers donne un prix inestimable, puisqu'elle permettra de combattre, par une diminution notable des constructions, la hausse toujours croissante des locations.

On nous assure que l'Empereur, dans une de ses récentes visites aux travaux du bois de Vincennes, a accordé une attention particulière à l'invention de MM. Coignet, et a paru fort satisfait de l'essai qu'ils en ont fait.

FERRÉ.

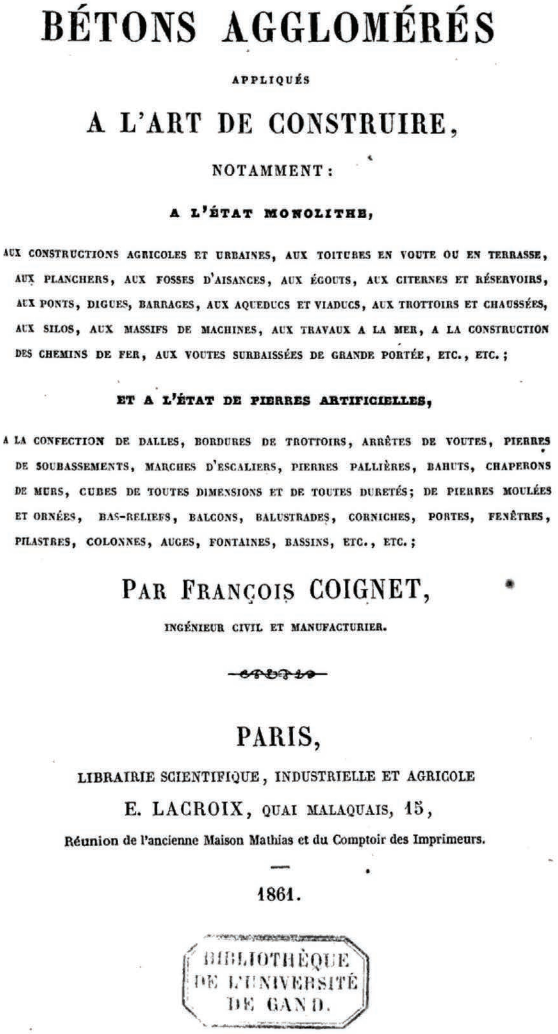
NOUVEAU MODE DE CONSTRUCTION EN BÉTON.

PAVILLON DE GARDE CONSTRUIT EN BETON AU BOIS DE VINCENNES.

Figure 1.3.16 General view and method of concrete construction of the guard's house in the Bois de Vincennes.

Source: *L'Illustration, Journal universel*, no. 805, (XXXII), 31 July 1858: 68. Photo credit: author.

In 1861, in his main work *Bétons agglomérés appliqués à l'art de construire notamment à l'état de monololithe et à l'état de pierres* (Figure 1.3.17), Coignet (1861) formulated an original theory on the hardening of concretes which his "analytical experiments" had taught him to master. According to him, the humidity diffused over time through old masonry walls allowed it to harden. The material's solidity was reinforced when, naturally or anthropogenically, coatings disappeared to directly expose the masonry to air and water. The mastery of this petrification process in the manufacture of agglomerated concretes by crushing and compacting had, he claimed, permitted "construction in elevation above the ground". This concrete or "endless stone" was intended for the construction of underground streets, theatres, baths and entire cities, that is structures likely to meet the needs of an ideal society of the Fourierist type, a movement to which Coignet was particularly attached.


BÉTONS AGGLOMÉRÉS

APPLIQUÉS

A L'ART DE CONSTRUIRE,

NOTAMMENT :

A L'ÉTAT MONOLITHE,

AUX CONSTRUCTIONS AGRICOLES ET URBAINES, AUX TOITURES EN VOUTE OU EN TERRASSE, AUX PLANCHERS, AUX FOSSES D'AISANCES, AUX ÉGOUTS, AUX CITERNES ET RÉSERVOIRS, AUX PONTS, DIGUES, BARRAGES, AUX AQUEDUCS ET VIADUCS, AUX TROTTOIRS ET CHAUSSÉES, AUX SILOS, AUX MASSIFS DE MACHINES, AUX TRAVAUX A LA MER, A LA CONSTRUCTION DES CHEMINS DE FER, AUX VOUTES SURBAISSÉES DE GRANDE PORTÉE, ETC., ETC. ;

ET A L'ÉTAT DE PIERRES ARTIFICIELLES,

A LA CONFECTION DE DALLES, BORDURES DE TROTTOIRS, ARRÊTES DE VOUTES, PIERRES DE SOUBASSEMENTS, MARCHES D'ESCALIERS, PIERRES PALLIÈRES, BAHUTS, CHAPERONS DE MURS, CUBES DE TOUTES DIMENSIONS ET DE TOUTES DURETÉS; DE PIERRES MOULÉES ET ORNÉES, BAS-RELIEFS, BALCONS, BALUSTRADES, CORNICHES, PORTES, FENÊTRES, PILASTRES, COLONNES, AUGES, FONTAINES, BASSINS, ETC., ETC. ;

PAR FRANÇOIS COIGNET,

INGÉNIEUR CIVIL ET MANUFACTURIER.

PARIS,

LIBRAIRIE SCIENTIFIQUE, INDUSTRIELLE ET AGRICOLE

E. LACROIX, QUAI MALAQUAIS, 15,

Réunion de l'ancienne Maison Mathias et du Comptoir des Imprimeurs.

1861.

Figure 1.3.17 Title page of *Des bétons agglomérés appliqués à l'art de construire* (Coignet 1861).

Source: The Getty Research Institute, Los Angeles.

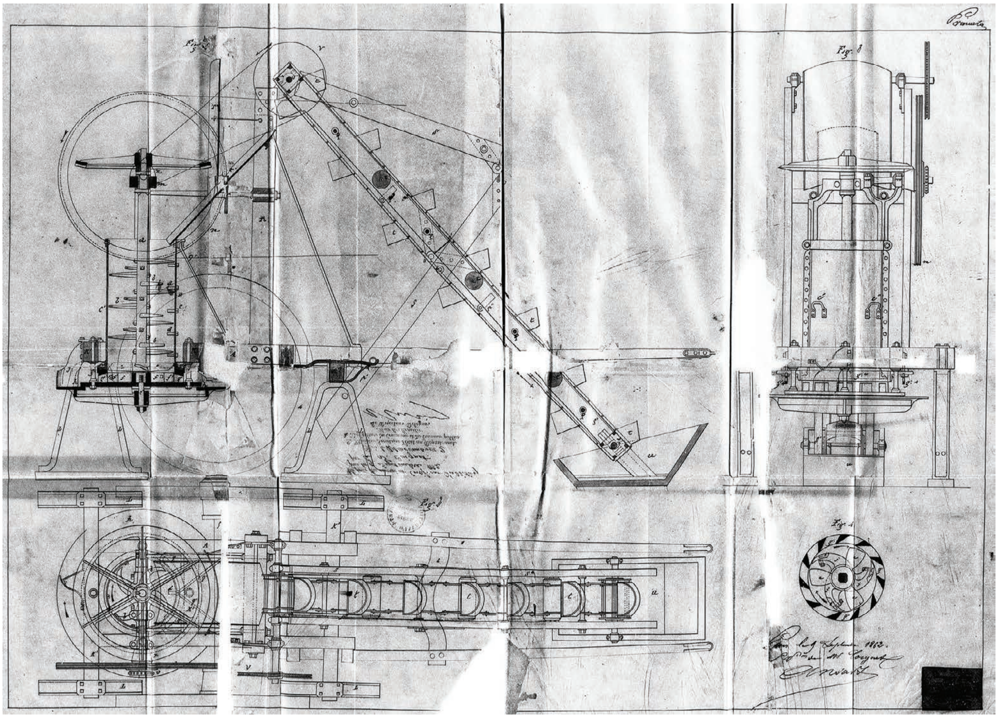


Figure 1.3.18 F. Coignet, apparatus for producing mortars for *bétons agglomérés*.

Source: Institut national de la propriété industrielle (INPI), Patent no. 45085 of 10 May 1860, updated on 9 September 1862. Photo credit: INPI.

From 1863, through the Société centrale des bétons agglomérés système Coignet, the inventor claimed to have made decisive advances in mechanized production (Figure 1.3.18), as well as in the manufacture of polychrome *bétons agglomérés* of various textures.

The masonry work on the church of Sainte-Marguerite in Le Vésinet, executed between 1862 and 1865, was his first major project; he showed great mastery of the appearance of his materials, whether moulded *in situ* or produced in the workshop (Figure 1.3.19). In a display of some virtuosity, he implemented hollow *modénatures* created using counter-frames fixed inside the wooden formwork. At the same time, he succeeded in inserting several artificial stone elements into the masonry, although it is not always easy to distinguish them on the façades of the current building. Polychrome concrete was used on the floor of the main nave, and high-strength concrete was applied in highly stressed structures, such as the bases of the cast-iron columns or the brackets of the gallery.

The construction of the fourth section of the Vanne aqueduct for Paris water supply, from 1868 onwards (Figure 1.3.20), remains the most important public works project in agglomerated concrete that has survived to the present day. The drawings were made by the engineer Eugène Belgrand (1810–1878). Many of the 60 km of aerial structures built still exist in the forest of Fontainebleau, some probably with their original coating. To reduce the cost of production, the impalpable Fontainebleau sand found on the site itself was used. Traces of the sturdy formwork are still visible on the arches' intrados, while the outer surfaces were given a thick protective layer of lime and sand.

Figure 1.3.19 F. Coignet and L.-A. Boileau, church at Vésinet near Paris (1863–1865), with details of the main façade. Photo credit: the author.

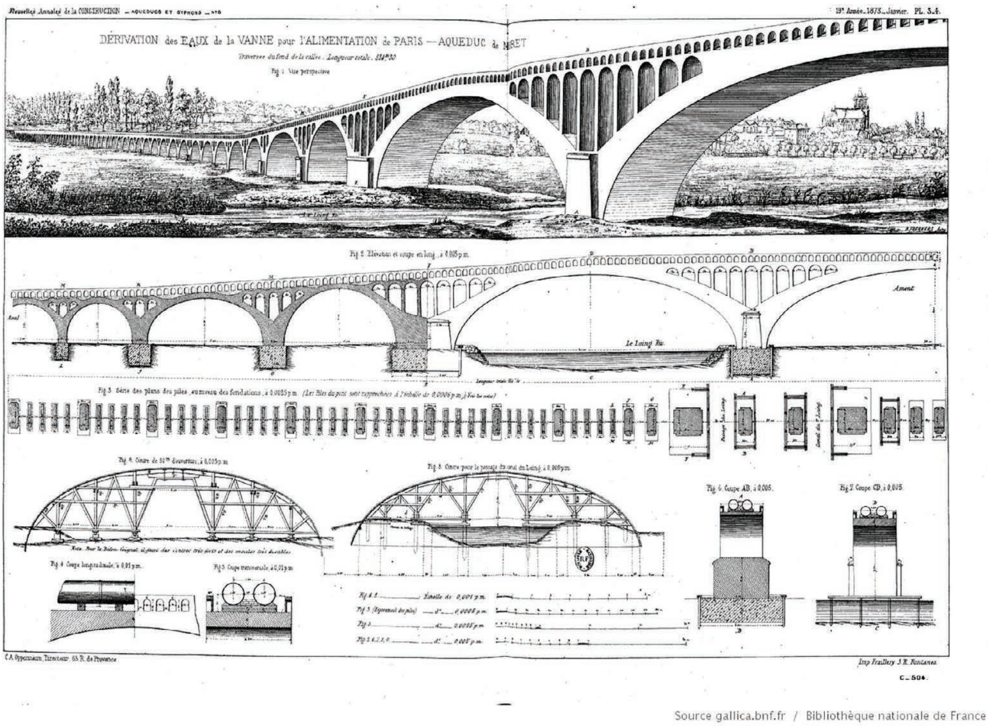


Figure 1.3.20 F. Coignet, the Vanne aqueduct (1869–1870), with general view and details of the construction of the Moret-sur-Loing aqueduct.

Source: *Nouvelles annales de la construction*, January 1873, pls. 3–4. Photo credit: BNF, Gallica.

Among other prestigious civil engineering works, the lighthouse at Port-Saïd in Egypt, commissioned by the Compagnie universelle du canal maritime de Suez, built from 1869 onwards, is worth mentioning. In terms of urban housing, three notable projects have been identified: a model company town in Saint-Denis and two buildings described as “ornate concrete houses” in Paris. While the buildings in the rue de la Terrasse are completely unknown today, visitors to the Universal Exhibition of 1867 were able to examine the “house” in the rue Miromesnil in detail. Stratigraphic studies carried out on the façades of the recently renovated *cité ouvrière* (company town) in Saint-Denis have confirmed the absence of coating on the exposed *béton aggloméré* masonry (Figure 1.3.21).

All the principles of application used at the time of construction can be identified today in these façades. Monolithic masonry built without reinforcement (including cornices and lintels) is combined with the insertion of artificial stone elements which are still clearly recognizable. By using prefabricated artificial stone, Coignet succeeded in clearly separating the masonry produced *in situ* from the manufacture of the ornamentation. The modelling and polychromy were to give this masonry an “appearance of unusual richness”. The rational use of these materials resulted in forms with strong horizontal lines corresponding to the ground level and very pronounced recessed vertical sequences which underline the monolithic character of the architecture of these ensembles.

Figure 1.3.21 F. Coignet, general view of the *cité ouvrière* at Saint-Denis, ca. 1871–1872.

Source: The author.

Coffered Materials and New Decorative Strategies: Viollet-le-Duc and the Emergence of a New Aesthetic Paradigm

In 1861, Coignet proclaimed himself the founder of "a new theory, if not a forgotten complement to the theory of M. Vicat" (Coignet 1861: 67) and even of a "revolution in the art of construction" (Coignet 1861: 15). The modernity of concrete was not in doubt at the time. For example, like Coignet but indirectly, Auguste Choisy in *L'Art de bâtir chez les Romains*, published in 1874, supports the idea that his contemporaries had surpassed everything that had been done since antiquity. Choisy states that "concrete was not the ordinary masonry of ancient walls" (Choisy 1873: 19). He thus dismisses the idea of an "analogy of manufacture" (Choisy 1873: 23) between the "massive castings in movable coffers" similar to those of rammed earth (Choisy 1873: 22) and the "construction concrète" (Choisy 1873: 215) or "in small masonry materials" of antiquity. According to Choisy, this ordinary masonry was "essentially based on the separate use of mortar and rock fragments". It had "all the advantages of concrete", but was much cheaper because it did not require any preparation, which "saved a good deal of the labour that would have been necessary for preliminary mixing" (Choisy 1873: 19). Coignet and Choisy refer, in effect, to the originality of a structural system associated with a new material, now directly placed on view. The constant references to these procedures in works devoted to masonry at the end of the century in France testify to the cultural anchoring of a material which was becoming part of the realm of the tangible: concrete construction was finally able enter the realm of architecture.[10]

Viollet-le-Duc's posthumous work *De la Décoration appliquée aux édifices*, published in Paris in 1880 (Figure 1.3.22), was undoubtedly a turning point for a new approach to these materials.

DE

LA DÉCORATION

APPLIQUÉE AUX ÉDIFICES

PAR

EUG.-EMM. VIOLLET-LE-DUC

A. BALLUE, ÉDITEUR

PARIS
LIBRAIRIE DE L'ART, 33, AVENUE DE L'OPÉRA

LONDON
134, NEW BOND STREET, 134

1880

Figure 1.3.22 Title page of *De la Décoration appliquée aux édifices* (Viollet-le-Duc 1880).
Source: The author.

First, the author questions the classical doctrine of the imitation and transposition of wood construction into stone construction:

> It has been repeated everywhere, both in great books and in simple pamphlets, on I do not know what primary data, more sentimental than critical, that Greek architecture – and then it was only the temples, as if all the architecture of a people consisted only of its religious buildings – was derived from the *wooden hut*. The unfortunate thing is that, while with a lot of goodwill one can establish some similarities between a work of carpentry and the Parthenon, for example, things get complicated if one goes looking for the buildings that preceded it, like the temples of Selinunte or those of Paestum.
>
> (Viollet-le-Duc 1880: 11)

He adds, "it takes a lot of imagination to see, in a Doric stone building from a primitive period, something reminiscent of the art of carpentry" (Viollet-le-Duc 1880: 11). Viollet-le-Duc suggests then that interlocked masonry was at the very origin of architecture. He writes:

> We can define very precisely the origins of the Egyptian structure [. . .] in interlocking rammed earth. It is even easier to find the origins of the Assyrian structure, since, except for the wooden cladding which is disappearing but whose appearance is still reproduced by architects, the same construction method is still used even in the most recent monuments of this people.
>
> (Viollet-le-Duc 1880: 11–12)

Thus, Viollet-le-Duc defined in the ancient world, in Egypt, what he called a "unity of structure" which had consequences for visual aspects: "It is obvious that these structural procedures did not permit any protruding carved decoration either on the exterior or on the interior" (Viollet-le-Duc 1880: 9). He continues:

> The decorative approach which consists in emphasizing, by means of contrasting large smooth surfaces, certain main points on which sculpture (the Stylobic bas-reliefs) and painting are then applied, belongs to these oriental countries, and was later adopted by the Arab architects. [. . .] This is evidently due to the nature of the structure, made of rammed earth, plastered stone blocks or raw or fired bricks; materials which did not allow the use of sculpture. [. . .] Sculpture was reserved [. . .] for the foundation platform of buildings.
>
> (Viollet-le-Duc 1880: 10)

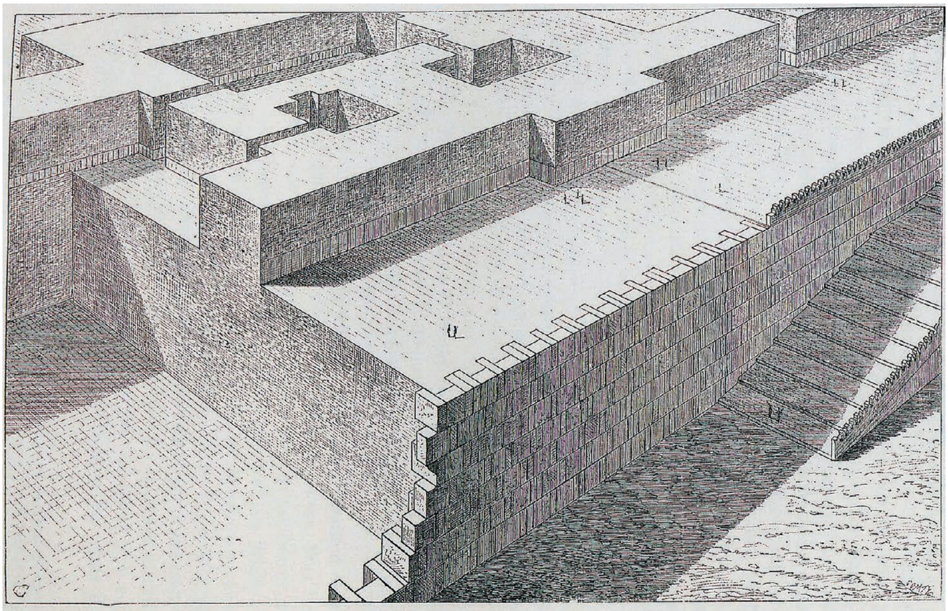
Following in Viollet-le-Duc's footsteps, one of his pupils, Charles Chipiez (1835–1901), was the author of the illustrations and also of some of the studies on ancient architecture in volume I, dedicated to Egypt, of the *Histoire de l'art dans l'antiquité*, *Egypte*, *Assyrie*, *Perse*, *Asie Mineure*, *Grèce*, *Etrurie*, *Rome*, published in collaboration with the archaeologist Georges Perrot (1832–1914) from 1882 onwards. The new determinism given to materials is strongly emphasized at the beginning of the work, where the authors state: "Of all the causes which influence the character of an architecture and which contribute to determining it, the one whose action can best be understood and foreseen is, therefore, the nature of the materials and what may be called their genius" (Perrot & Chipiez 1882: 106). They distinguish two types of construction, which they call "compact" and "assemblage". The processes of

> compact construction allows the use of considerable quantities of damp earth mixed with chopped straw; in this way, buildings are constructed in a sense of one single piece. This material is poured and compacted between wooden boards; these form a sort of mould which can be removed once the earth has taken its shape; but the density of the building elements . . . is always very low; it is far from being comparable to that of those agglomerated materials which are called concrete, and which take on the consistency of very hard stone.
>
> (Perrot & Chipiez 1882: 115)

A complete system of compact construction is also recognized, thanks to the vaults that allowed "covering the spaces with rammed earth" (Perrot & Chipiez 1882: 115). The authors add (Figure 1.3.23):

> Used in a damp state, the raw brick of the buildings in and around Nineveh is almost adobe; it is more likely to be related to what we have called compact construction than to the construction of structures. [. . .] The building, in fact, was all in one block [. . .] one can imagine the building as cast in a colossal mould that would have been filled with trodden earth.
>
> (Perrot & Chipiez 1884: 154)

This renewal of the aetiology of architecture brought back into the limelight the so-called substitute materials and, more specifically, the monolithic construction model characteristic



47. — Le palais de Sargon, partie sud-ouest. Vue perspective et coupe. D'après le géométral de Place, t. III, pl. 20 et 35.

Figure 1.3.23 Bird's-eye view of Sargon's palace, Khorsabad (Iraq), 8th century BC (Perrot & Chipiez 1884: II, 150).

Source: Heidelberg University Library.

of the structural process of early modern concrete. Above all, it paved the way for changes in aesthetic positions in architecture. The work of two architects, Gaspard André (1840–1896) and Tony Garnier (1869–1948), who worked in Lyon – the region where these techniques were particularly developed – can go some way towards illustrating these transformations. Local circumstances were quite favourable for the use of these new materials. From 1872 onwards, the road regulations of the city of Lyon, while still forbidding the use of rammed earth, which had been disqualified since the flooding of the city in 1856, classified *pisé de mâchefer* as "masonry". Its use was even encouraged in 1901 by a new system of taxes intended to replace the duties on building materials, which had been imposed in an equivalent manner until then. The floors of houses built with clinker concrete were from that point taxed half as much as those built with cut stone. This new condition significantly accelerated the transformation of the economy of the building site. The construction by the departmental architect Antonin Louvier (1818–1892) of vaults in clinker concrete in the basements of the Rhône prefecture from 1880 onwards shows that neo-vernacular and empirical techniques such as clinker concrete had also made technical progress. Trained at the École des Beaux-Arts in Paris and twice awarded second place in the Grand Prix de Rome in 1865 and 1870, Gaspard André adopted this material from the beginning of his career, and in 1883 for the construction of a vast silk-dyeing factory (Figure 1.3.24) on the banks of the Saône river in Lyon, commissioned by the Gillet family.[11]

The building, which no longer exists, comprised a high façade 250 m long, punctuated by square blind towers covered by flat roofs and animated by low, double segmental arches supported by colossal piers. Ornamentation in cement *moulé au gabarit* ("moulded to size", i.e. profiled on a lime coating applied after removing the moulds) drew bandeaus and plinths on these smooth walls to form continuous horizontal lines. In 1889, when François II Gillet's house in Izieux in the Loire department was being extended, André used a wide range of decorations on clinker concrete, sometimes set into the masonry, such as the stone brackets of the balconies, and sometimes profiled or applied to the surface, such as cement tiles. In 1893, the project for the thermal baths of Évian-les-Bains in the department of Haute-Savoie used walls and vaults made of clinker concrete (Figure 1.3.25). White bricks covered the façades, and the horizontal lines of the flat roofs accentuated the sober lines of the architecture of the complex.

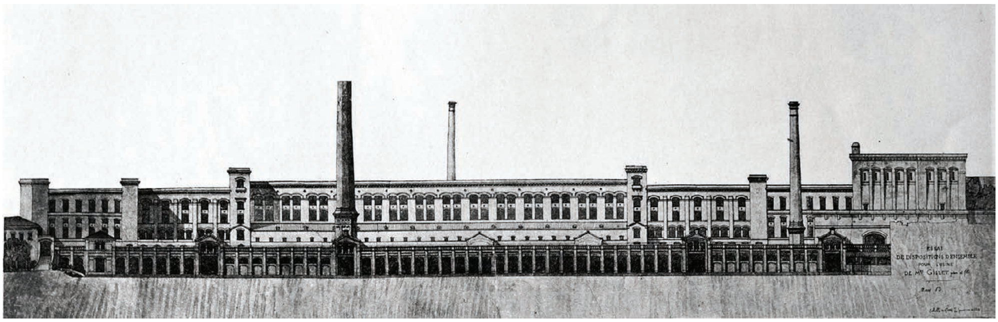


Figure 1.3.24 Gaspard André's design for the Gillet's silk-dyeing factory in Lyon, 1883.

Source: *L'Œuvre de Gaspard André* [1897–1898], pl. 38; Photo credit: Atelier d'imagerie.

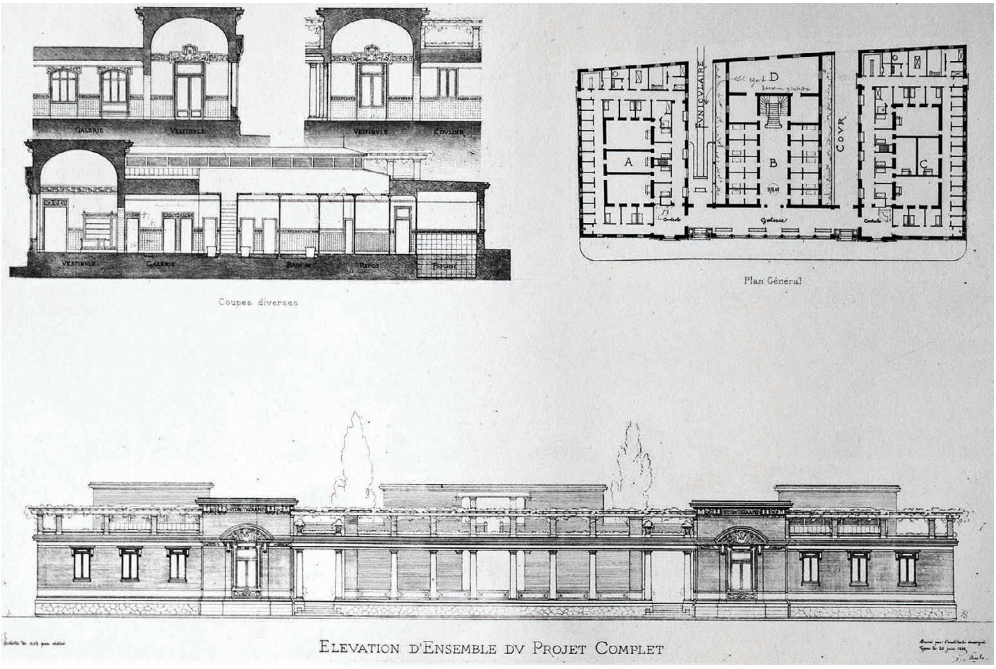


Figure 1.3.25 Design for the thermal baths of Évian-les-Bains, 1893 (André & Aynard 1898: pl. 86).

Source: Atelier d'imagerie.

Two years later, the façades of the Hôtel Balaÿ, on Place Puvis de Chavannes in Lyon – also built in clinker concrete for the Gillet family – were to be "left unpainted [. . .], with no visible connection; in a word, as if they had been taken from a single block of ashlar",[12] according to a company's estimate. Even though he had been one of its fiercest detractors since the reform of the École des Beaux-Arts in 1863, André undoubtedly read *De la Décoration appliquée aux édifices* with great interest. The work in his library resonated with his extensive experience of formwork masonry. The use of simple forms directly derived from the implementation and the "genius" of the material are undoubtedly due to the influence of Viollet-le-Duc. And the architect's late project of a large "Evangelical Christian Church", designed a few months before his death and intended to be exhibited at the Salon de la *Société Nationale des Beaux-Arts*, bears witness to an aesthetic achievement that cannot be isolated from the use of cast masonry (Figure 1.3.26). The walls, vaults and the 18-m diameter dome would be made of clinker concrete and covered with flat roofs.[13] Thus, some 3,000 worshippers would have found themselves before a sort of primitive church made up of parallelepipedal blocks with little ornamentation under an empty blue sky.

This project was inspired by the "Restitution du temple de Jérusalem d'après Ézéchiel", the "temple des temps futurs" ("temple of future times") in biblical tradition, published by Charles Chipiez (1835–1901) and Georges Perrot (1832–1914) in 1885,[14] but, in fact, it probably referred more to Viollet-le-Duc in the rationalism of soberness and simplicity specific to this type of masonry, which gives it a timeless character. Only ten years separate these projects

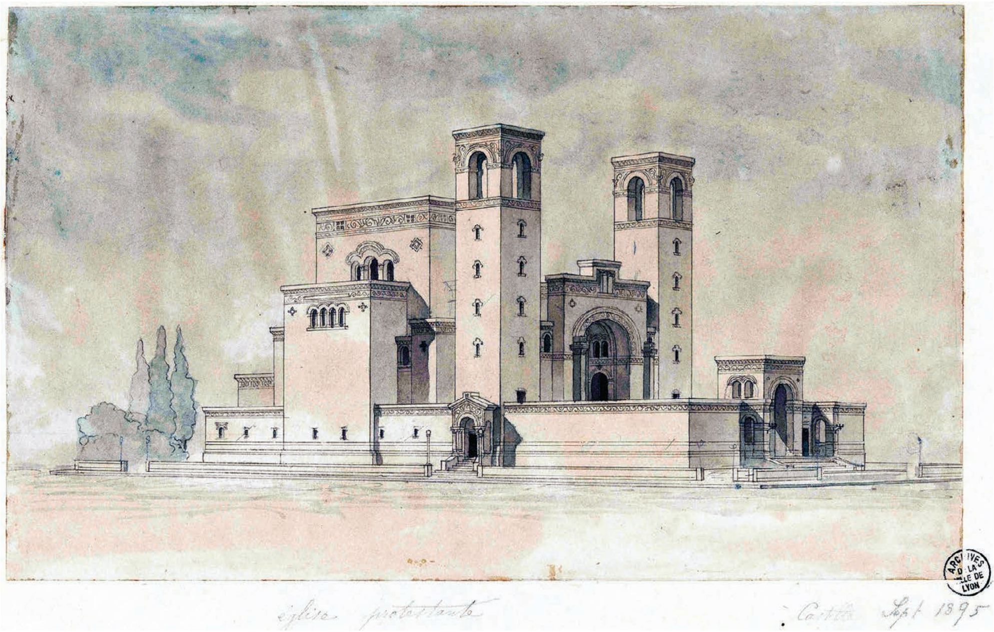


Figure 1.3.26 G. André, perspective of a protestant church, 1896.

Source: Archives municipales de Lyon, 33 II 78. Photo credit: Archives municipales de Lyon.

from the first achievements of Tony Garnier, whose work can be considered today as the culmination of the first concrete techniques.[15] Trained at the École des Beaux-Arts in Lyon (and under Louvier, then at the École des Beaux-Arts in Paris where he was awarded the Grand Prix de Rome in 1899), Garnier is best known for his plans for an "industrial city". This project was contemporary to his restitution drawings of the Roman Forum Tabularium in 1901, which featured his dedication, condemning ancient architecture,[16] which was later withdrawn from an exhibition of the work of the boarders at the French Academy in Rome. Garnier eventually also produced a restitution plan of the ancient city of Tusculum in 1904, a work that is still very little known.

The *Cité industrielle* (Figure 1.3.27) was finally published in its final version in 1918 with 184 plates (Garnier 1918). After locating his city quite precisely in "the region of south-eastern France" in his short introductory text, Garnier specifically mentions the "materials used in this region which will be employed by us as a means of construction" (Garnier 1918: 1). In the first two lines of the final paragraph of his introduction entitled "Construction", he further states that these materials are "gravel concrete for foundations and walls, and reinforced cement for floors and roofs. All important buildings are built with reinforced cement" (Garnier 1918: 5). The three types of formwork masonries mentioned are fairly recent and undoubtedly signal a certain form of modernity at the time when Garnier describes them as being used in the main for the construction of his *Cité*. Another aspect of this modernity, underlined by Garnier, is the aesthetic consequences of the use of the same family of materials employing a common structural system on which his architecture is said to be based,

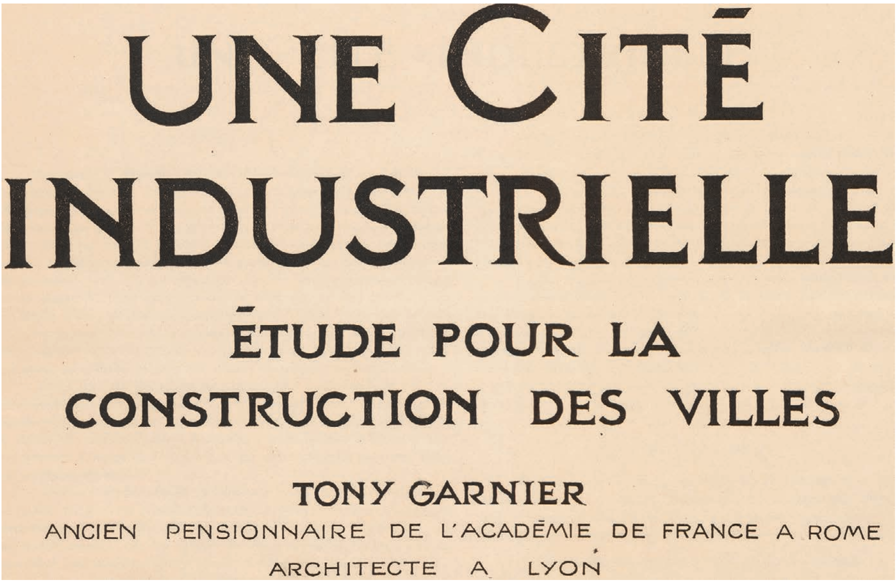

UNE CITÉ
INDUSTRIELLE
ÉTUDE POUR LA
CONSTRUCTION DES VILLES
TONY GARNIER
ANCIEN PENSIONNAIRE DE L'ACADÉMIE DE FRANCE A ROME
ARCHITECTE A LYON

Figure 1.3.27 Title page of *Une Cité industrielle* (Garnier 1918).

Source: Laboratoire de Recherche Historique Rhône-Alpes.

as we shall see. By subtitling his work "Étude pour la construction des villes", Garnier also seems to indicate that constructive practice and the use of materials are central themes that determine his work.

The dairy building of the Vacherie du Parc de la Tête d'Or was the architect's first commission on his return to Lyon in 1904. The building is constructed in gravel concrete for the foundations and clinker concrete for the walls (Figure 1.3.28). The façades were left without any relief; in other words, any operation after the formwork had been removed, except for the application of a coating and then a limewash. A contemporary describes the construction "Without any ornament, without the slightest moulding, the walls made of cement-coated clinker concrete, milky white" (Tuotiop 1906: 124–125).

From his first project, as if continuing in some way the initial approach, André Garnier accentuated the simplicity and plastic qualities of this early concrete.[17] He seems to have retained from Viollet-le-Duc and Chipiez the rational logic of the use of materials rather than the myth of a new narrative on the origins of architecture. A modest, utilitarian building succeeds the religious building, the evangelical church, which traditionally represents (as in André) the matrix type of architecture.

Shortly after the first drawings for the Vacherie, on 30 November, Garnier signed the designs for his "Villas en bordure du parc de la Tête d'or" (Figure 1.3.29). It can be assumed that these villas for the upper-middle classes, like the neighbouring Hôtel Balaÿ built ten years earlier, were also built of *pisé de mâchefer*.[18]

Like those of La Vacherie, the stepped gable walls are typical of the use of this material, as confirmed by one of the first known photographs of a clinker concrete building site in 1907 (Figure 1.3.30). One is surprised to note the constructive and formal logic stated by Chipiez

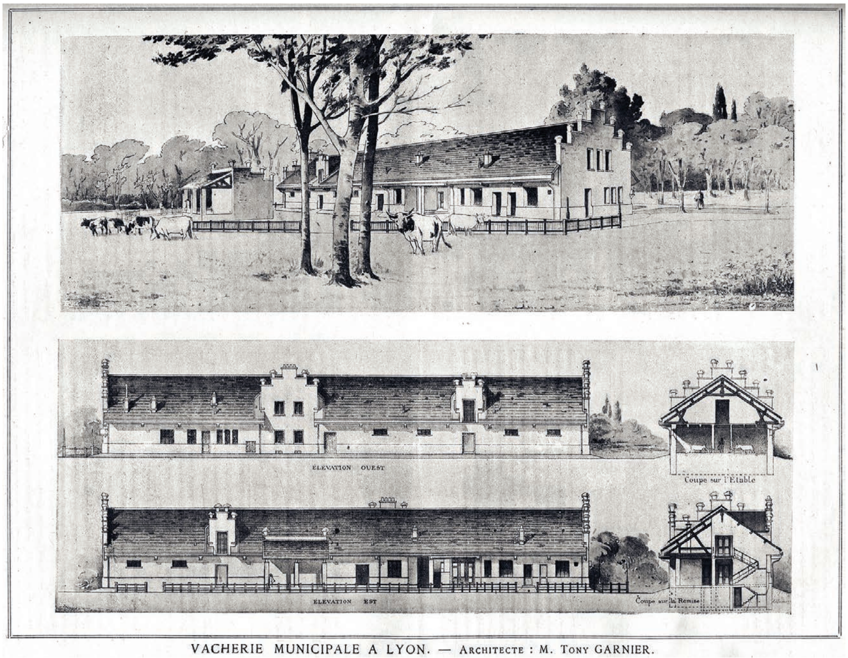


Figure 1.3.28 T. Garnier, design for the Vacherie du Parc de la Tête d'Or, Lyon, 1904–1905.

Source: *La Construction lyonnaise*, 1 June 1906; 127. Photo Bibliothèque municipale de Lyon.

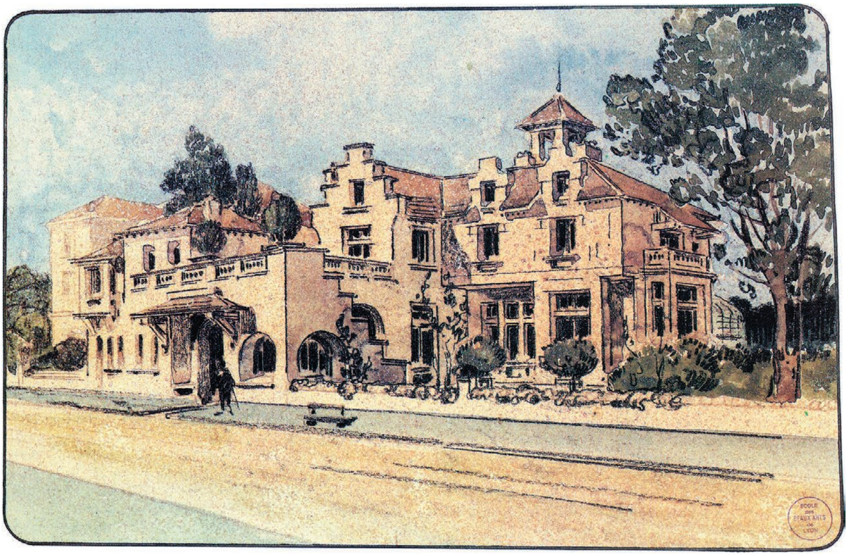


Figure 1.3.29 T. Garnier, perspective of dwelling houses near the Parc de la Tête d'Or, Lyon, *ca*. December 1904.

Source: Musée des Beaux-Arts de Lyon. Photo credit: Musée des Beaux-Arts de Lyon.

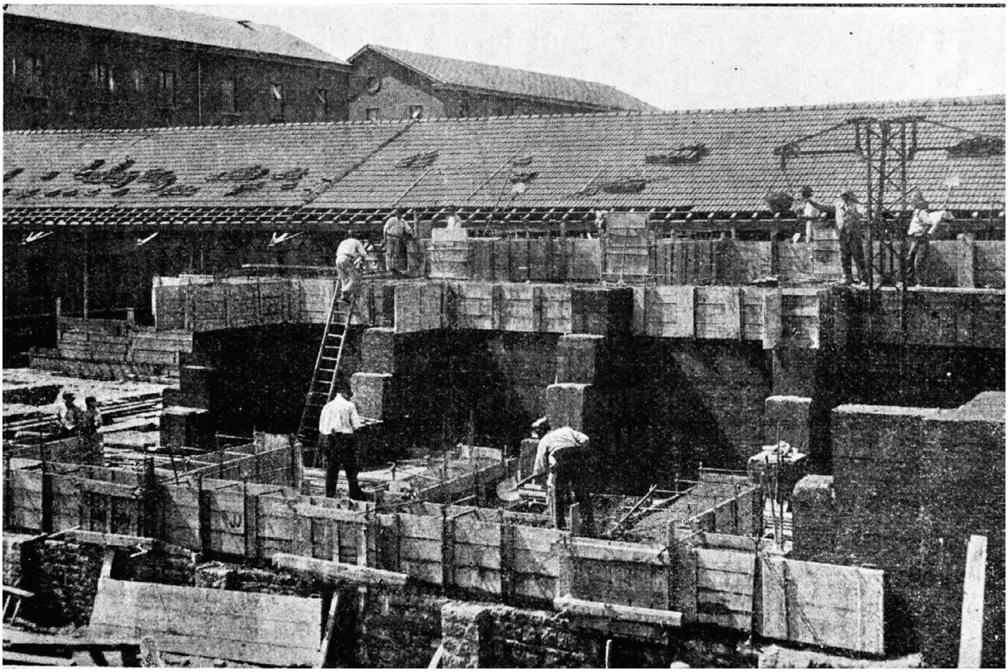


Figure 1.3.30 General view of a site of *pisé de mâchefer* at the Moulins de Perrache, Lyon, *ca*. 1907.

Source: *La Construction lyonnaise*, 1913. Photo credit: Bibliothèque municipale de Lyon.

concerning the crenelations of oriental buildings where the "system of apparatus regulates the form, dimension and distribution" and leads, according to him, to "a form which [is] the direct result and the very expression of the system of construction where it plays an important role" (Perrot & Chipiez 1884: II, 236–267, figs. 102–106).

Garnier also succeeded in completing the formulation of an architecture specific to this structural system thanks to the arrival of a new, related technique: reinforced concrete. Its mastery, as well as its use in key and highly stressed areas of the buildings, allowed him to consolidate his aesthetic project. Until the second half of the 1890s and André's house, for example, massive clinker concrete arches ensured the passage from one wall to another. At La Vacherie, a *ciment armé* (reinforced cement) floor designed by the engineer Louis Coularou is complemented with clinker concrete walls.[19] As can be seen from the request he sent on 8 October 1903 from Rome to a former student, Paul Guichard, concerning the price "in volume" of the new material and "the most interesting work published on the use of reinforced cement",[20] Garnier seems to have been introduced to this technique at a later stage. At the time, it was mainly used for the construction of floors, as shown by the local work of Coularou and the Hennebique company.[21] This technique was undoubtedly part of the initial plans for the Vacherie, as the competing project had already foreseen that "the floor of the first floor would be rendered in reinforced concrete".[22] There is, however, a major difference between the two architects in their use of this technique. In Duret's case, the reinforced concrete floor has no "expression", to use Garnier's terminology. It remains confined to the interior of the building;

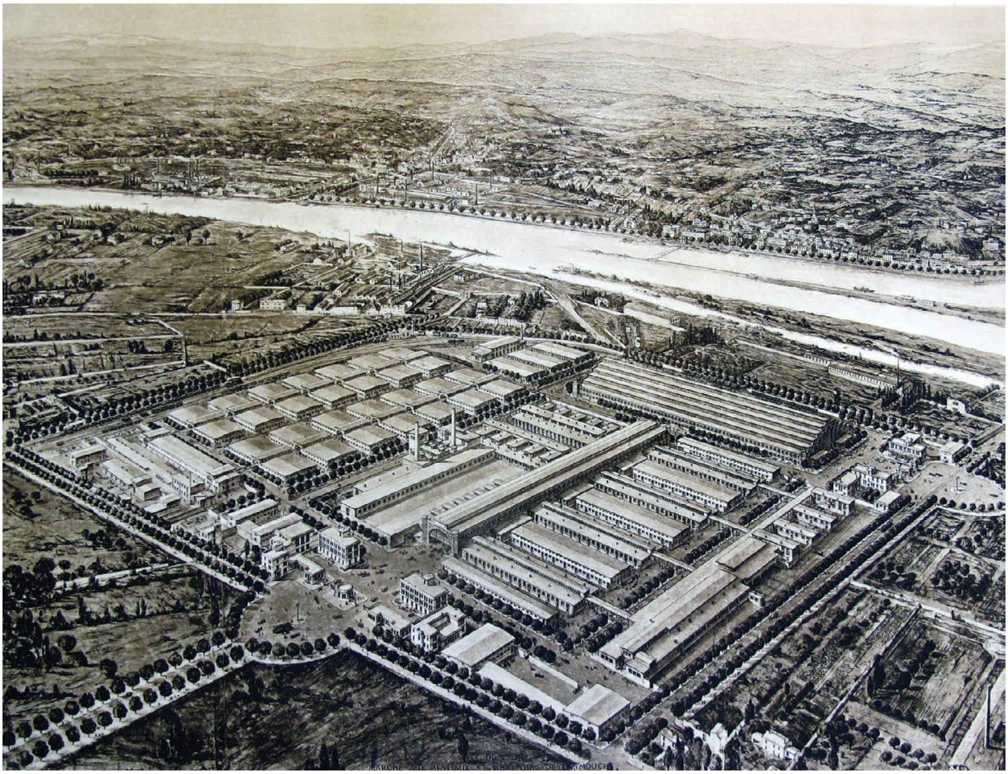


Figure 1.3.31 Bird's-eye view of the slaughterhouse of La Mouche at Lyon, 1909.
Source: *L'Architecte*, 1909, pl. XXXII. Photo credit: the author.

in other words, it is restricted to transmitting the significant loads expected on the walls and pillars, and there is nothing to distinguish the use of this technique on the façade. It is the framework that extends outside and forms canopies as in traditional agricultural buildings. In Garnier's case, on the other hand, the reinforced concrete floor tops the clinker concrete walls and extends to the outside in a wide cantilever incorporating the gutters and supported by reinforced concrete brackets (1.30 m). With this combination, the floor is no longer simply superimposed or assembled, but associated with and integrated into the masonry of the walls to which it is attached.[23] Apart from the roof, which remains traditional, the building becomes a monolithic structure, which was also a *topoï* feature of innovative masonry in the 19th century.[24] However, Garnier's exclusive use of reinforced concrete was to be an exception.[25] Even though he indicated in 1918 that this material was dedicated to the "important" buildings of his Cité, in fact he mainly used plain concrete, that is clinker or gravel concrete.[26] It is even this association that partly determines, if not forms the whole foundations of, Garnier's architecture. As early as July 1908, a bird's-eye view of the Gerland abattoirs (Figure 1.3.31) shows annex buildings whose silhouettes are similar to those of the industrial buildings of the *Cité industrielle* (Garnier 1918: pl. 163).

A general view of the "Quartier industriel du tissage de la soie" (fabric block for silk weaving) also shows, at the same time and for the first time, residential buildings covered in terraces and therefore entirely monolithic (Guiheux et al. 1989: 84–86).[27] Garnier went further than his predecessors, however, in formulating what he saw as the links between the use of these new and unconventional materials and the emergence of a new aesthetic. The form of the buildings "expresses" these materials and their use and vice versa:

> These two materials [gravel concrete and reinforced concrete] are used fresh in moulds prepared for this purpose. The simpler the coffers are, the easier the construction will be, and consequently the cheaper it will be. This simplicity of means logically leads to a simplicity of expression in the structure.
>
> (Guiheux et al. 1989: 84–86)

Formulating his decorative strategies was certainly also Garnier's way of echoing, if not paying homage to Viollet-le-Duc:

> Let us note, moreover, that if our structure remains simple, without ornament, without moulding, bare throughout, we can then dispose of the decorative arts in all their forms, and that each object of art will retain its expression all the more clearly and purely because it will be independent of the construction.
>
> (Garnier 1928: [5])

This rapid survey of the first types of concrete in France gives an account of some of the main currents running through the history of the creation of new masonry in France at the end of the modern era. Scholarship and vernacular techniques were first combined to restore the ancient *emplekton* and then to imagine a kind of lithogenesis destined to the development of new substitute materials. The accession of these materials to the realm of architecture during the 19th century – their arrival in the realm of the visible and the tangible – was accompanied by a certain idea of modernity and new behaviours. Garnier's first projects, such as his house (Figure 1.3.32) in Saint-Rambert-l'Île-Barbe near Lyon (1911) or the abattoirs in Gerland, are particularly representative in this respect.

The advent of reinforced concrete roof terraces completes the constitution of a single family of formwork materials that are distributed in a rational manner (plain concrete is used for the walls and reinforced concrete for the floors and roofs). This combination is used to create an aesthetic made up of simple volumes, with rectilinear lines (clean and pure, in Garnier's terms), allowing, in both residential and industrial buildings, the assembly and repetition that a project requires for the construction of a modern city, now imagined as a whole (Figure 1.3.33).

The unprecedented proliferation of postcards of the Mouche slaughterhouse site shows how large-scale construction methods and a new aesthetic were disseminated from 1911 onwards (Figure 1.3.34).

Before the publication of the *Cité Industrielle*, this site – like that of the Grange Blanche hospital (Figure 1.3.35), which was at the time of the First World War one of the largest concrete architecture sites of modern times – illustrates the emergence of a new link between architecture and construction practices.[28]

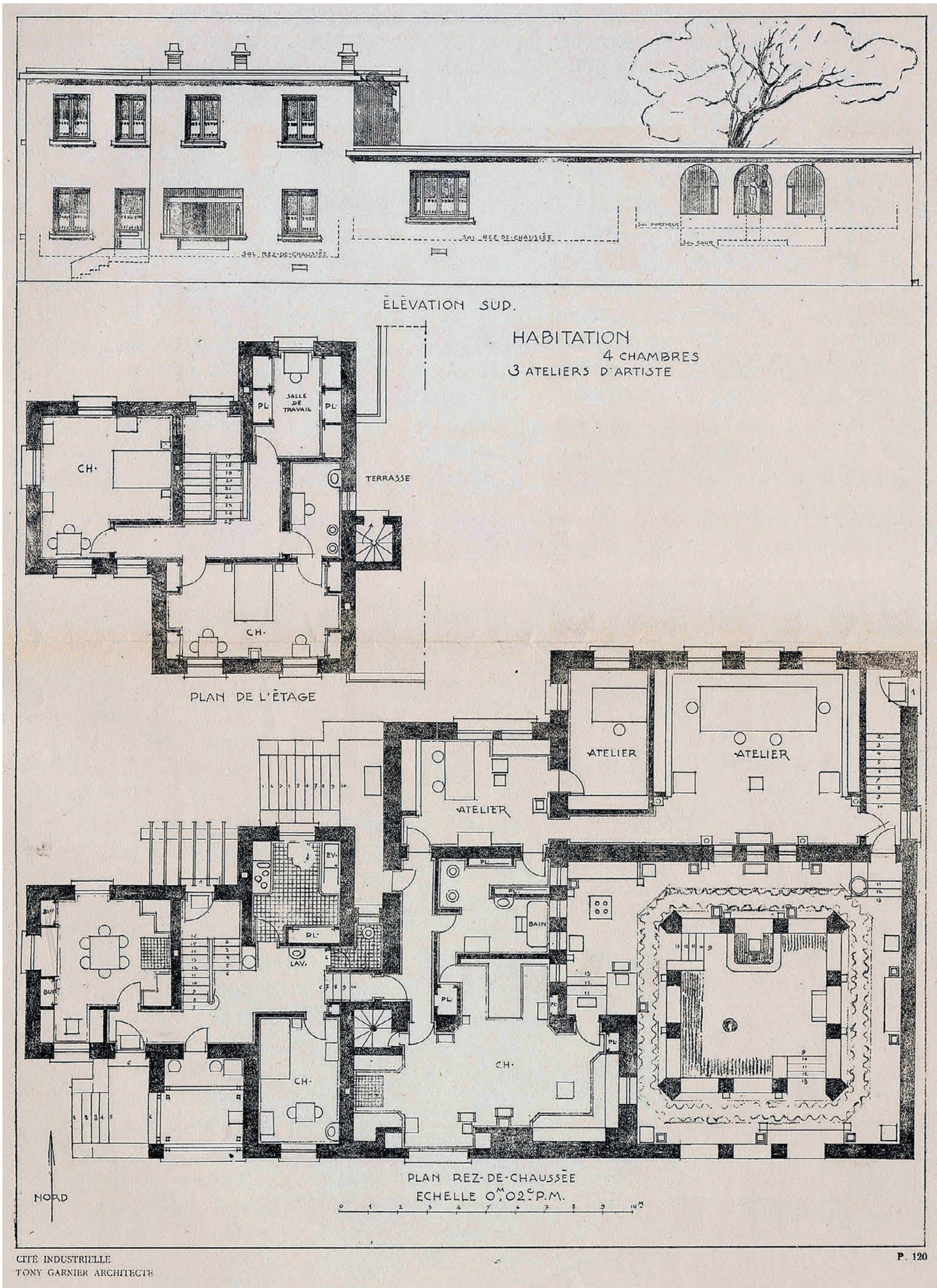


Figure 1.3.32 Plan and elevation of Garnier's villa at Saint-Rambert-l'Île-Barbe near Lyon, 1911–1912 (Garnier 1918: pl. 120).

Source: Laboratoire de Recherche Historique Rhône-Alpes. Photo credit: J.-P. Collet.

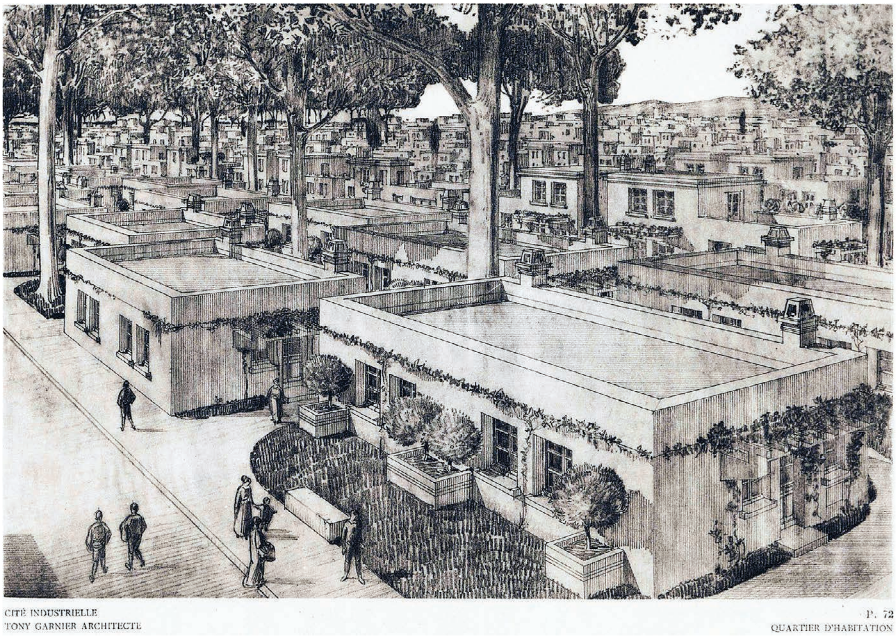


Figure 1.3.33 General view of the *Quartier d'habitation* de la Cité industrielle (Garnier 1918: pl. 72).

Source: Laboratoire de Recherche Historique Rhône-Alpes. Photo credit: J.-P. Collet.

Figure 1.3.34 Anonymous, photograph of an "Avenue" of the Slaughterhouse of La Mouche at Lyon, *ca.* 1913–1914.

Source: Archives municipales de Lyon, 4FI18. Photo credit: G. Vernasconi.

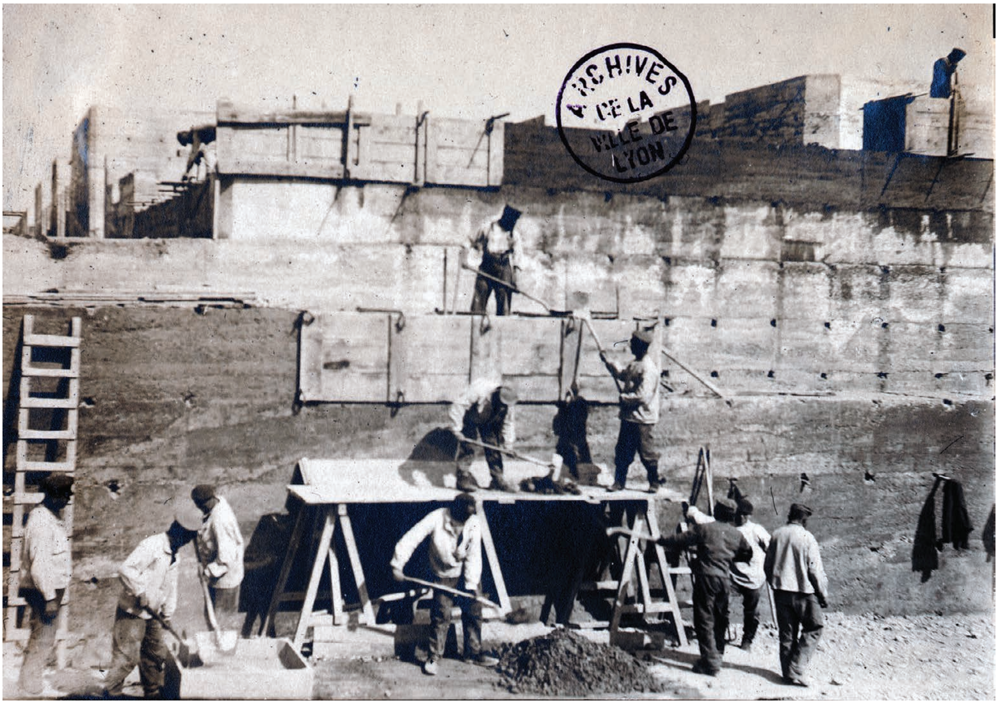


Figure 1.3.35 Anonymous, photograph of the site of the Hospital Grange Blanche at Lyon, *ca.* 1915.

Source: Archives municipales de Lyon, 959WP140. Photo credit: G. Vernasconi.

Notes

1 On these editions, see Nègre (2010: 366).
2 On Cointeraux and the spread of the rammed earth technique, see Baridon et al. (2016).
3 The garden pavilion known as the Emperor's Pavilion at the Château de Malmaison was built in 1792 for Jacques-Jean Le Couteulx du Molay. Its originality lies in its construction in "new adobe", which allowed walls to be built that were octagonal on the outside, painted in fresco, circular on the inside and covered by a dome which was probably destroyed around 1840.
4 For the illustration of the formwork (pl. II, Figure B), see Veihelmann (2015: 425). Dieussart also features the "muri di cementi" by Palladio (pl. III, Figure D).
5 On these two inventors, see mainly Nègre (2016: 137–155).
6 The following year, Abbé Rozier published the article "Pisai ou pisé" in Volume VII of the *Cours complet d'agriculture . . . ou Dictionnaire universel l'agriculture* by the architect Catherin François Boulard (1749–1793). Boulard reproduces the text of the first known manuscript on this subject, dated 17 March 1745, by Guillaume Marie Delorme (1700–1782), a hydraulic engineer and garden specialist, under whom Boulard had studied. In his *Recherches sur les aqueducs de Lyon*, Delorme is also one of the first to compare the technique used to build the local ancient aqueducts with that of *pisé de terre* (Delorme 1760: 64).
7 Archives Nationales de France (ANF), O1 1294–182.
8 Rondelet devotes a long chapter (article VI) to "Masonry with filling in rough stones or blockwork", that is "The third species [of masonry] called by the Greeks *emplecton*" (340–344).
9 On this architect, see Rico (2001).
10 See for example "Bétons agglomérés-système Coignet" (Oslet & Chaix 1890: 150–160).

11 On Gaspard André, see *L'œuvre de Gaspard André*, Lyon, A. Storck (1898) and (Richaud 2015: 416–420); Id., *Gaspard André architecte (1840–1896). Une préfiguration de la modernité* (forthcoming).
12 Archives Municipales de Lyon, 212 II, Estimate by the company Convert et Ellia, 29 June 1895.
13 "Holzcement" is the intended technique for waterproofing these flat roofs. In 1893, André learned about its use from Georg Lassius (1835–1928) at the Zurich School of Chemistry. This product of German origin, known as "ciment volcanique" ("volcanic cement"), is cited as "the most widespread for this use" by Paul Christophe (1902: 490).
14 André explicitly quotes this author (Perrot & Chipiez 1882–1914) on a sketch of a Protestant temple on 2 January 1885 (Archives Municipales de Lyon, 212 II).
15 On Garnier, see mainly Guiheux, Cinquelabre & Toutcheff (1989) and Faivre D'Arcier, Mourad & Rojas-Perrin (2019). On Garnier's material culture, see Richaud (2015, 2016, 2018b, 2022).
16 "Like all architecture based on false principles, ancient architecture is a mistake. Truth alone is beautiful. In architecture, truth is the result of calculations made to satisfy known needs with known means" (Anonymous 1901).
17 Garnier completely renounced the use of profiled cement ornaments in a city where there was a real know-how in this field, as shown by the presence of more than 20 companies and nearly 300 workers dedicated to this type of work in Lyon in 1906 (AFAS 1906: I, 404).
18 Entrepreneurs reported in 1907 that "all the villas or private hotels", "the luxury buildings" that were built in the Parc de la Tête-d'Or "only paid the 3rd category tax, the walls being made of mâchefer" (*Bulletin du Syndicat des Architectes du Rhône*, no. 5, October–November 1907: 18). On the project for the villas near the Parc de la Tête d'Or and its dating, see Bertin and Vaisse (2007: 92–101).
19 While many reinforced cement floor construction systems had recently been developed (Monnier, Matrai, Hennebique, Boussiron, etc.), Garnier chose Coularou's system, of which he was undoubtedly aware from the presentation leaflet published in 1903 under the title *Le béton armé et ses applications*.
20 Letter from Garnier to Jean-Paul Guichard (1872–1942), dated 8 October 1903 (Archives départementales et de la Métropole du Rhône, ADMR): "My dear Guichard, could you give me these two pieces of information. 1° What is the price of reinforced cement (volumes) What is the most interesting published work on the use of reinforced cement. Thank you very much". Guichard could then advise him of two main works published in Paris the previous year: that of the Belgian engineer Paul Christophe (Christophe 1902) and that of the architect Catherin Berger and the engineer V. Guillerme (Berger Guillerme 1902). Catherin Berger (1870–1925) had met Garnier at the École des Beaux-Arts in Lyon; he joined his agency in 1905.
21 "Reinforced cement concrete is much less frequently used in the construction of walls than in the construction of floors and single supports" (Christophe 1902: 140). For the implementation of these elements, see Christophe (1902: 430–439). On Paul Cristophe, see Hellebois and Espion (2013).
22 Letter from Duret to V. Augagneur, 30 January 1904, (Archives Municipales de Lyon, 1140WP100).
23 These floors were still very expensive, and the Vacherie floor is no exception. The Coularou floor represents half the total cost of the masonry. Cristophe suggests amounts that are almost ten times higher. This technique was therefore reserved for specific structures that were very demanding in terms of loads.
24 Lebrun built the walls and vaults of his brother's house in concrete in 1828, and Coignet made small experimental buildings entirely of agglomerated concrete in the late 1850s. In 1902, Paul Christophe took up the theme of monolithism on numerous occasions with regard to the advantages of reinforced concrete.
25 As an example, two isolated projects can be cited: the "Construction en béton de ciment armé" on the edge of the Parc de la Tête-d'Or in Lyon, dated 30 November 1904, and the project for the competition for the Rothschild Foundation in Paris, dated 7 December 1905 (Guiheux et al. 1989: 59, 80–81).
26 Ordinary concrete and clinker concrete (*pisé de mâchefer*), as at La Vacherie, had the same price (11 Francs/m^3).
27 The project of a "Municipal school, healthy housing", dated 15 August 1918, succeeds it and presents similar characteristics (Guiheux et al. 1989: 87; ADMR, 118J169). Garnier may have been inspired by an ordinary concrete house with a flat roof and staircase built in 1872 in Germany by the Berlin Cement-Bau AG (Aprea 2016: 216).
28 Some 150 civilians and 500 German prisoners handled more than 35,000 m^3 of gravel concrete to raise to the ground floor, that is for their underground parts, about 10 of the 20 pavilions planned on 15 hectares.

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Chapter 1.4

Institutions Within a New Material

Early Reinforced Concrete in Switzerland and Germany

Mario Rinke

Introduction: Ideological Conflicts

Like many other European countries, Switzerland and Germany underwent far-reaching social transformations at the turn of the 20th century.[1] Many architectural debates on modern construction and its role in expressing a new modern paradigm have considered programmed construction materials crucial in this development.[2] Unlike structural iron or subsequently steel throughout the 19th century, reinforced concrete was not firmly attributed to the progressive movement when it emerged on the scene. While the professional community praised its synthetic character – it could be applied to almost any possible form, providing high robustness, compactness and impermeability, thus representing a further improvement on steel structures – others celebrated reinforced concrete more as a kind of advanced stone that facilitated a classic monumental image seriously eroded during the dominant steel period (Rinke 2012). Technological modernization and a strong trend for the reconstitution of traditionalist ambitions are the extreme positions which can be read and easily distinguished in the early applications of this material, symbolizing progress or decay in the art of building (Jost 2006). This dichotomy is fully evident in industry exhibitions where the latest technology was demonstrated in the form of pavilions or other small-scale structures which were nevertheless given a conventional form. Figure 1.4.1 shows the Exhibition bridge of Dyckerhoff & Widmann at the Gewerbeausstellung in Duesseldorf in 1880, a perfect example in which technical and representative forms collide (Stegmann 2011).

One earlier case in Switzerland demonstrates the contemporary debate more subtly but quite vividly. For the new Stauffacher Bridge in Zürich, spanning 40 m in total, the city opted for a free-spanning bridge, and the young structural engineer Robert Maillart (1872–1940) from the internal engineering department proposed a three-hinged single-arch bridge in unreinforced concrete with a rising height of 3.7 m (Figure 1.4.2). Compared to other proposals, the concrete proposal turned out to be by far the cheapest option. While the bridge's concrete construction was highly innovative, its external appearance was designed by the city architect Gustav Gull (1858–1942) who cladded the concrete structure with natural stone, mainly granite (SBZ 1899).

The example of the Stauffacher Bridge clearly illustrates the entanglement of several contemporary entities and their contributions, which all came together in the pragmatic application of this new material. While the cement industry provided a capable material based on a high-quality cement, the structural engineers and the contractor applied it to a structural typology, the three-hinged arch. Both material and structure exceeded conventional technical limits. The city authorities and architects formally defined what was needed (the clear span and traditional outer appearance), thereby separating the use of the material from its visual presentation.

DOI: 10.1201/9781003368656-6

Figure 1.4.1 Exhibition pavilion of Dyckerhoff & Widmann at the Bayrische Landesausstellung in Nuremberg in 1906.

Source: Archive Knut Stegmann.

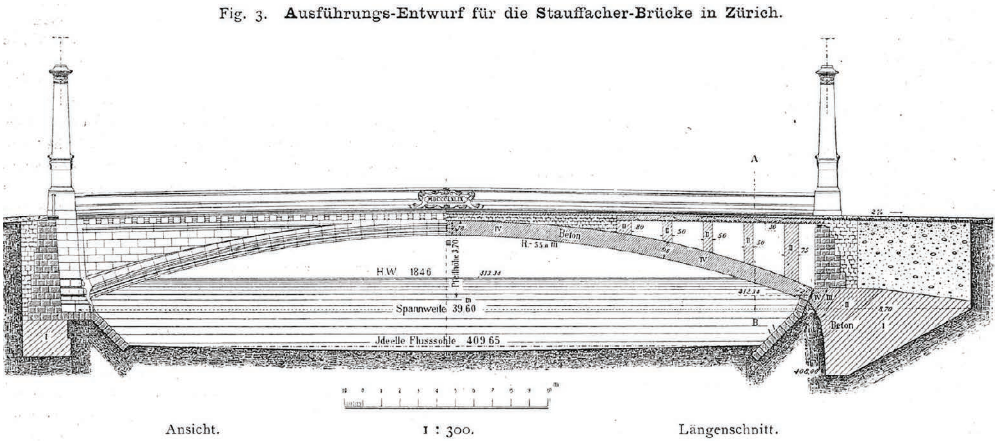


Figure 1.4.2 Stauffacher Bridge in Zürich, Engineer Robert Maillart, 1899.

Source: Schweizerische Bauzeitung, 33, 9, 1899: 83.

The particular involvement of these institutions suggests an ongoing process of development and formation within the field of reinforced concrete applications at the beginning of the 20th century. Looking at the establishment and the role of the new material, we should, therefore, focus on the first steps in Switzerland and Germany. Who was involved? How was reinforced concrete shaped beyond the form we perceive? How was the early culture developed and by whom? To describe the agency of the institutions involved in a simplified form, industry, including material fabrication and building construction, can be situated on the manufacturing and application side, while science – both within academia or in the industry – reflects and explains the matter; and administrative bodies organize and oversee the legal framework, for example with regulations and patents.

Dissemination and Recognition: The Building Industry

François Hennebique (1842–1921), a French entrepreneur who opened his internationally operating office in Paris in 1892, patented his construction method of reinforced concrete in Switzerland in February 1893 (Hennebique 1893). Four years later, he patented three more applications: slabs, piles and sheet piles and the controlled bending and overlapping of steel bars in continuous beams. As he chose foreign agents to establish an international network, the Swiss engineer Samuel de Mollins (1845–1912) from Lausanne joined him and helped to establish contacts with key figures within both public authorities and industry (Gubler 1985). As early as September 1892, de Mollins demonstrated a reinforced concrete floor on the basis of Hennebique system in Lausanne, and, as of that date, it was regularly featured in the technical press.[3]

In Germany, the case was somewhat different. Although some local contractors applied Hennebique's methods and held his license (e.g. Martenstein & Josseaux or Eduard Züblin), there were problems with building authorities unable to verify the design documents. Hennebique permanently faced intense competition from other reinforced concrete "systems" on many national markets he entered, and German rivals took advantage of early efforts to publish their design and construction methods to gain support from the authorities (Kierdorf 2009). Freytag & Heidschuch and Martenstein & Josseaux had acquired the German Monier patent (DRP 14673 from 1880) earlier on, in 1884, and developed their own theoretical and practical knowledge with the help of new construction technology. Gustav Adolf Wayss (1851–1917), together with the engineer Mathias Koenen (1849–1924), subsequently became the leading figure developing reinforced concrete in Germany with his company Actien-Gesellschaft für Monierbauten, which was known as Wayss & Freytag later.

According to the Hennebique archives, reinforced concrete developed quite quickly in Switzerland where its high robustness was appreciated. Other major advantages included high live loads with relatively little material, multi-storey construction and possible variations to column patterns, higher ductility avoiding sudden collapses, better fire safety and lower vibrations due to its higher self-weight. In terms of costs, the Hennebique system proved to be cheaper, especially for heavily loaded structures (Ritter 1899: 41).

However, beyond the early acceptance from potential clients and the engineers and architects' community, it was the material industry itself that made significant steps to increase publicity and acceptance. Thus, as early as 1890, the young cement manufacturer Jura built the first reinforced concrete bridge in Switzerland on its site to span the Aare canal running through their plot (Figure 1.4.3).

The extremely slender structure, built by the Actien-Gesellschaft für Monierbauten, with a span of 37.20 m and rising only 3.50 m, demonstrated a careful and precise material application and constructional execution (Maillart 1934: 2) up until it was torn down only in 1973 – even though it was still fully functioning. This showcasing of material technology on company premises was a compelling early image of reinforced concrete that visualized

Figure 1.4.3 First reinforced concrete bridge in Switzerland spanning the Aare canal in Wildegg, Actien-Gesellschaft für Monierbauten, 1890.

Source: Maillart (1934: 2).

both its strength and its feasibility. In their technical facet, visibly serving the permanent and reliable purpose of transportation, bridges have often served as valid demonstrations of new and controversial construction methods or materials. Some 100 years before Joseph Monier (1823–1906) built his bridge at Chazelet in France in 1875, one of the largest iron manufacturers in England, Abraham Darby III (1750–1791), built the first full iron bridge in his town of Coalbrookdale in 1879, spanning 30.60 m. The bridge was widely celebrated for the revolutionary technical breakthrough of the new construction material used and the iconic example provided by the structure for its further application in architecture and engineering (Briggs 1979: 59–104).

For its first large-scale infrastructure projects, Switzerland had to import Portland cement from Germany and France where the first factories making it opened in the middle of the 19th century. The industrial Robert Vigier (1843–1884) recognized the material's great potential and opened a factory close to Solothurn in 1871 (Figure 1.4.4), followed by a second one in Saint-Sulpice in 1877 and a third in Aarau in 1880. Most other cement manufacturers were founded before 1914. While production volume was rather insignificant, quality was considered already very good even in the early years (Hubler 2015).[4]

Just like their German rivals, Swiss manufacturers showcased the potential of their material at industrial exhibitions. Vigier presented a concrete structure at the Swiss Industrial Exhibition of 1883, for example (Figure 1.4.5).

Again, using the example of a bridge which spanned some 6 m, the manufacturer aimed to demonstrate the high capability of the material, referring to the load-carrying and necessarily dependable nature of this structure.

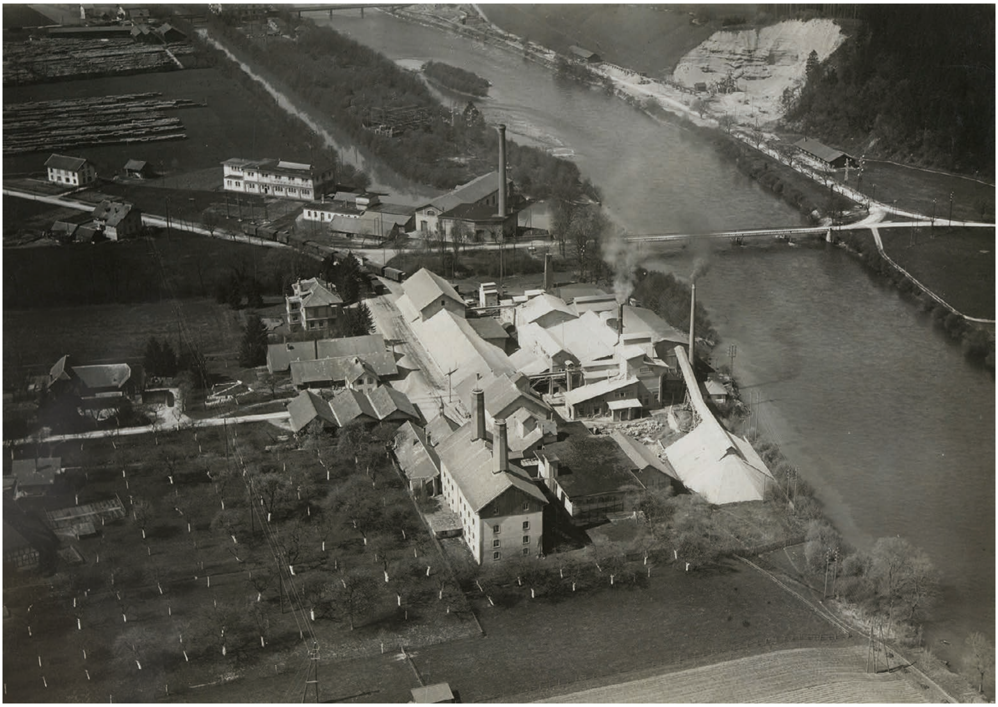


Figure 1.4.4 Robert Vigier's first cement factory close to Solothurn, 1871.
Source: ETH-Bibliothek Zuerich, Bildarchiv.

Mediation and Regulation: Building Administration

Framing the Basis for the Material

As the material industry was increasingly organized and growing, industry players sought recognition through authorities, calling for a regulation of ingredients, general terminology and material properties. Beyond their purpose of building trust, together with import taxes, the rules helped to protect local industry against the much larger manufacturers from Germany and France. The first cement code in Switzerland was introduced in 1881. The leading figure behind its development was Ludwig Tetmajer (1850–1905), alumni of the polytechnic school in Zürich (the eidgenössische polytechnische Schule, now ETH Zürich). After serving as an assistant to engineering professor Karl Culmann (1821–1881) and becoming a professor in 1878, he was appointed first director of the Building Materials Testing Institute, now the Swiss Federal Laboratories for Materials Science and Technology (EMPA), founded in 1880. Not only in its first code but also the first revisions to it, the EMPA worked closely with cement manufacturers and the Swiss industry body Verein Schweizerischer Zement-, Kalk- und Gips-Fabrikanten (VSCKGF), an important lobby organization of Swiss cement, lime and gypsum manufacturers founded in 1881 (Hiestand 2011: 293–294). In 1910, Switzerland was able to cover its own national demand for cement for the first time.

The first Portland cement factories in Germany opened in 1850 close to Hamburg, and others soon followed in Northern Germany. In 1877, German cement producers founded their industry

Figure 1.4.5 Concrete bridge by Robert Vigier at the Swiss National Exhibition in Zürich, 1883.

Source: Romedo Guler, ETH-Bibliothek Zuerich, Bildarchiv.

association, and, in 1878, the Prussian administration issued regulations for the provision and testing of Portland cement following discussions within the Berliner Architekten-Verein (Berlin Architects' Association). This new regulation was also discussed in Switzerland when the country's first code was being developed. The Association opened a testing laboratory in 1902 in Berlin and regularly published technical reports, setting the foundations for a broadly established industry-based material research tradition. This institutionalized zone enabled the industry to pursue specific applied research questions outside the individual interests of single companies. In contrast, in Switzerland, the laboratory material research at the EMPA stood for an institutionalized zone of public–private collaboration, namely between the polytechnic and the industry. These zones outside or in between the institutions were characterized by interconnected interests and needs, which lead to an environment of consensus operation. Based on the concept of operating institutions – with individuals moving from one to another or holding positions in more than one institution – these zones can be considered contact zones where the representatives of cooperating institutions operate in an environment that is characteristically different from their original fields. This site of social and cultural encounters maintains its proprietary interests but is dependent on its contributing institutions.

Flaws of the Constructional Practice

On the construction side, building contractors developed the Hennebique and the Monier systems further with their engineering departments. It was a growing market with many new applications – industrial, public and also private buildings. Based on the principles of the successful core technology of Hennebique and Monier using continuous steel bars or meshes working together with the enclosing concrete (Rinke 2018), many further inventions and patents refined the practicality and effectiveness of construction. These often sought to bypass the necessary licenses of other patent holders, which is why there were at times dozens of systems on the market (Bussell 1996).

But there were also backlashes, accidents and failures of the new material, leading to occasional crises of trust and doubts as to its overall eligibility. The most decisive in Switzerland, with repercussions far beyond national borders, was the accident on 28 August 1901 when the Hotel zum Bären in Basel collapsed during construction. A group of experts was set up to investigate the failure: Arnold Geiser (1844–1909), Zürich's city architect; Wilhelm Ritter (1847–1906), professor at the polytechnic in Zürich and François Schuele (1860–1925), Tetmajer's successor as director of EMPA as of 1901. They found that a reinforced concrete beam in the ground floor, although made according to the plans, caused, together with its inappropriate support, the collapse of the facade and internal parts of the building. The detailed report not only gives insights into the defects of this specific building but also offers a comprehensive overview of contemporary design and building practice (SBZ 1902b).

The hotel in Basel was in line with the common Hennebique construction practice which strictly separated design from construction knowledge (Schlimme 2012; Delhumeau 1999). Accordingly, structural calculations and detailing were produced by the Hennebique office in Paris, along with all construction drawings. The construction details and sequence were not checked by the contractor in Basel, the Basler Baugesellschaft, leading to a complete separation of technical planning and execution. Typically for the design practice at that time, the knowledge of modelling and specification of all parts of a full reinforced concrete building remained exclusively with Hennebique or other patent holders, and documents were mostly not even issued to the client (Rauhut 2015). In this manner, powerful contractors established a quasi-standard of construction, which was tolerated by the building authorities and not yet critically monitored by the academic institutions. In the Basel case, the contractor knew about the construction method and had used it before. From extensive field observations and laboratory tests, the experts concluded that the concrete mixture, the formwork as well as the layout of the reinforcement bars were all satisfactory. They claimed, though, that the necessary compression strength of the concrete was not achieved, and that the calculation method used lead to unsatisfactory steel reinforcement.

However, the main reason for the collapse was believed to be the early lowering of the props and stripping of the formwork. The entire construction process was very rushed, both during planning and execution, and there was no checking of the material properties on-site or the general process by the architects. Therefore, the experts suggested that the Hennebique method was not in question in this case; rather, the problem lay with the design and construction practice. Furthermore, the commission acknowledged that there are many different systems subsumed under the term "Hennebique" and that there was no thorough scientific basis for the design of reinforced concrete structures whatsoever, which is why the system needed refining, and execution ought to be guided and carried out with the utmost care.

This accident was a significant event for both the building industry and the authorities alike. They had to re-establish trust not only in the general safety of construction but also specifically in the reinforced concrete technology. The situation was similar to that of the catastrophic railway accident of Muenchenstein on 14 June 1891, only ten years before the Basel collapse. It was the worst railway accident ever to affect Switzerland, in which a crowded passenger train crashed into the river Birs, killing more than 70 people.

Similarly in that case, a special commission issued a report, delivered by Ludwig von Tetmajer from EMPA and Wilhelm Ritter from the polytechnic school in Zürich (Ritter & Tetmajer 1891). They found that the iron truss bridge had failed due to an insufficient structural capacity and detailing. As a consequence, Swiss railway bridges have been systematically checked since, and the first bridge design code was issued on 19 August 1892, only 14 months after the accident.

The Construction of Codes: The Guideline Approach in Switzerland

The initiative for the first concrete code was launched by planning architects and engineers and the material industry. The Swiss Society of Engineers and Architects (SIA) and Swiss Cement Industry Association set up a commission to elaborate on the issue and come up with a proposal. However, before that commission had produced any outcome, the SIA issued provisional regulations in 1903 accompanied by an explanatory introduction by François Schuele from the EMPA (SBZ 1902a). Thanks to the wealth of detail available on the publication of this regulation and its development, it is possible to trace the main parties involved and their perspectives. According to the internal structure of the SIA, they developed the regulations bottom-up: in May 1902, the central committee of the SIA asked all regional sections to make proposals for the regulations. Three of those sections preferred general recommendations; five of them asked for detailed specifications (SBZ 1904).[5]

In his introduction, Schuele gives a better understanding of the nature of these regulations and how the building design industry sees the need for such. He frames the main goal as necessary control: the regulation should be primarily a guideline for contractors and authorities.[6] The document comprised six pages and specified the loads to be assumed, key calculation aspects such as acceptable continuity effects, the stiffness ratio of steel and concrete, allowable stresses for the steel bars and the concrete used for the compound, general material qualities and several aspects of construction such as striking times and checks during the construction process. However, two overarching aspects characterize the Swiss approach quite well, which coincide with the philosophy of the regulation as a guideline, as Schuele put it. First, the specification aimed to be as general as possible and highly practicable, excluding technical issues which are not theoretically understood (e.g. width of the ribs below a slab) or experienced in practice or which would deal with an unnecessary level of scientific depth (e.g. complete calculation methods). By touching only on the aspects essential and necessary to securing a higher safety standard, the Swiss authors of the regulations aimed to avoid providing a recipe either for design or construction. The dominant position of the existing building practice can be better understood via the explanation which effectively excluded a questioning of the construction system as such by defining the role of the code as a guardrail. The code, therefore, should not affect existing buildings: “The code should adopt healthy practice.

It should only call something deficient where it has been recognized to be of lower quality or dangerous but not tighten construction or design methods that have not caused any problems" (SBZ 1904: 151 [translation by the author]).

In this way, the regulation would reflect and codify the experience and, in turn, the pragmatism of the industry. Swiss regulations, which tend towards the general, usually avoid tenacious constraints and instead allow for exceptions, as they are explicitly implemented as the last paragraph of the document in this case: "Exceptions: Regarding the novelty of these specifications, modifications on the rules as mentioned above are permissible if they are justified by comprehensive experiments and the judgments of competent experts" (SBZ 1904: 16 [translation by author]).

The guiding principles of the Swiss regulation are, therefore, a sound knowledge of the building practice and, more importantly, individual responsibility. Since the regulatory framework is founded on empiricism, architects, engineers and contractors are given a lead role in defining what this material technology actually is. And by leaving the loophole of exceptions, an active role remained for them to push the technology further with their initiatives. This partially open framework still exists, allowing for exceptions in the concrete code even today.

Consequently, checking the plans during the planning process, the qualifications of workers on site and the building process in general would have meant much additional effort for the building authorities. It would have also required highly qualified and trained staff or expertise from a third party, which is why it was only recommended for exceptional cases, while for regular buildings, standard checks were sufficient. The degree of safety was to be specified using allowable limits for stresses, and the cement quality should ideally be standardized.[7] Two years later, the Swiss Federal Railways (SBB) issued their own regulation for reinforced concrete, explicitly excluding empirical formulas – standard, for instance, in Hennebique's design practice – and these required every structural part to be load tested, which mostly applied to bridges and slabs in buildings.

A first significant challenge to the new regulation was another building collapse in August 1905 in Bern, shortly after its implementation (Figure 1.4.6). A survey report was prepared by Edouard Elskes, deputy chief engineer of the SBB head office and, again, François Schuele. In the partly published report, Schuele claimed that the provisional code was not to blame but rather its application (SBZ 1906: 115–137).

Neither the authorities nor the architect and engineer were said to have made adequate use of the code. As a consequence, an official commission was set up by Federal Government (Ministry of the Interior) in January 1906 with members from the SIA, the National Association of Cities and the Association of the Swiss Cement Industry – that is to say, all the stakeholders in building construction. After numerous series of laboratory tests at the EMPA (Figure 1.4.7), the first official code was issued in 1909. According to Schuele, a great deal of experience was needed to gain in-depth and reliable knowledge about the construction method; that is there were more observations necessary with built structures or further and more refined laboratory tests.

Again, an overly detailed calculation procedure was not considered reasonable, given the many unknown factors influencing the material. The document eventually featured 13 pages of regulations plus 23 pages of explanations.

The Construction of a "Scientific" Code in Germany

Similar to Switzerland, the first guidelines in the German Empire were issued by the Union of all German engineers and architects' associations together with the German Concrete Association

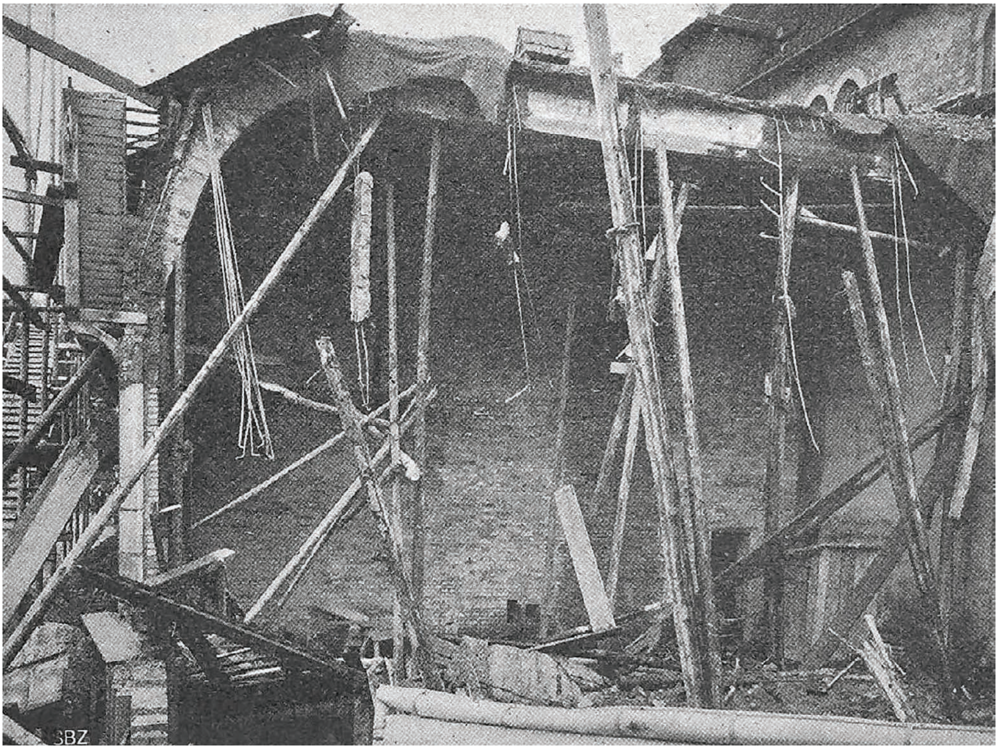


Figure 1.4.6 Collapse of a concrete building under construction, Bern, 1905 (Der Einsturz des Theaterdekorationsmagazins in Bern am 23 August 1905).

Source: *Schweizerische Bauzeitung*, 47/48, 10, 1906: 115–137.

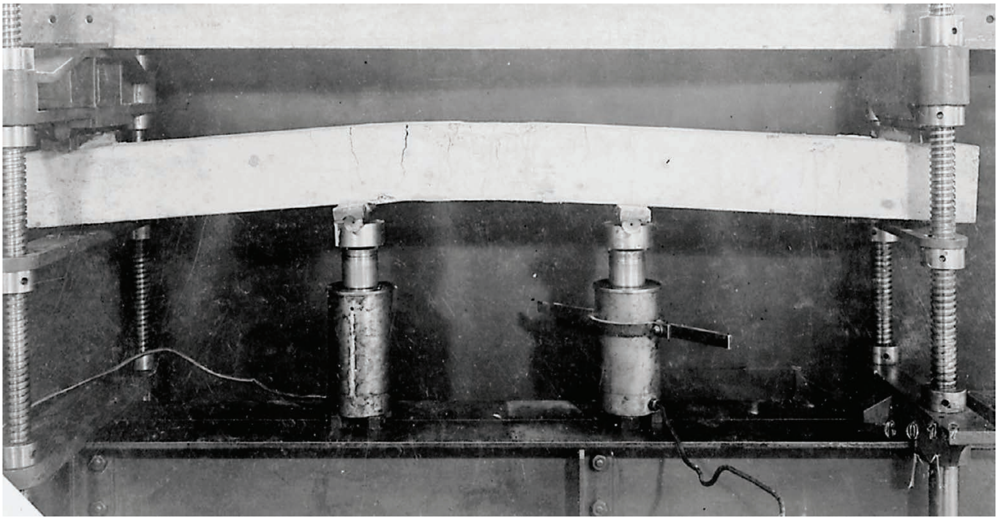
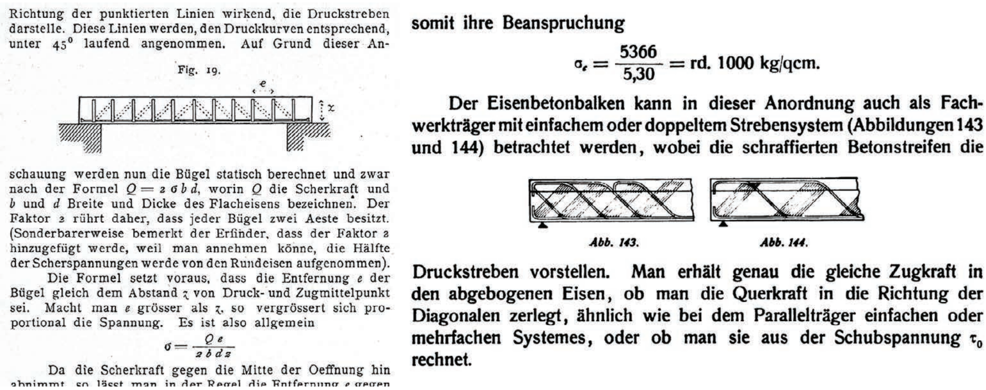


Figure 1.4.7 Material testing at the Swiss Federal Laboratories for Materials Science and Technology (EMPA).

Source: ETH-Bibliothek Zuerich, Bildarchiv.



Richtung der punktierten Linien wirkend, die Druckstreben darstelle. Diese Linien werden, den Druckkurven entsprechend, unter 45° laufend angenommen. Auf Grund dieser An-

Fig. 19.

schauung werden nun die Bügel statisch berechnet und zwar nach der Formel $Q = 2\sigma b d$, worin Q die Scherkraft und b und d Breite und Dicke des Flacheisens bezeichnen. Der Faktor 2 rührt daher, dass jeder Bügel zwei Aeste besitzt. (Sonderbarerweise bemerkt der Erfinder, dass der Faktor 2 hinzugefügt werde, weil man annehmen könne, die Hälfte der Scherspannungen werde von den Rundeisen aufgenommen).

Die Formel setzt voraus, dass die Entfernung e der Bügel gleich dem Abstand z von Druck- und Zugmittelpunkt sei. Macht man e grösser als z, so vergrössert sich proportional die Spannung. Es ist also allgemein

$$\sigma = \frac{Q e}{2 b d z}$$

Da die Scherkraft gegen die Mitte der Oeffnung hin abnimmt, so lässt man in der Regel die Entfernung e gegen

somit ihre Beanspruchung

$$\sigma_e = \frac{5366}{5,30} = \text{rd. } 1000 \text{ kg/qcm.}$$

Der Eisenbetonbalken kann in dieser Anordnung auch als Fachwerkträger mit einfachem oder doppeltem Strebensystem (Abbildungen 143 und 144) betrachtet werden, wobei die schraffierten Betonstreifen die

Abb. 143. *Abb. 144.*

Druckstreben vorstellen. Man erhält genau die gleiche Zugkraft in den abgebogenen Eisen, ob man die Querkraft in die Richtung der Diagonalen zerlegt, ähnlich wie bei dem Parallelträger einfachen oder mehrfachen Systemes, oder ob man sie aus der Schubspannung τ_0 rechnet.

Figure 1.4.8 Modelling shear stresses based on graphic statics. Left: Wilhelm Ritter (1899: 33/34, 5). Right: Emil Moersch.

in 1904. They are comparable to the Swiss regulations but gave way more constructional details.[8] There was even an almost identical rule for exceptions bypassing the strict regime of the technical framework.

In contrast to its Swiss counterpart, however, in the appendix, the specifications gave detailed methods for design calculation including many examples, representing the recipe principle which was avoided as a matter of great importance in Switzerland.

In 1907, the Prussian ministry issued specifications,[9] again giving detailed construction design and calculation methods. Compared with the Swiss code, the critical difference is the significant role of the authorities who have the overall control: of the design, the contractor and execution. The building authority was to approve all building designs if any construction began on the building site. The contractor had to prove building safety with detailed calculations, and the design calculations had to follow the given methods in the specifications. The code was, therefore, much more a textbook than a guideline – as perceived in Switzerland – and it did not allow, after the first guidelines from 1904, exceptions on the basis of empirical tests. The underlying regime of theoretical modelling and scientific proof through calculation established the central role in defining the nature of the material technology, while the institutional figures of science, in the name of theoretical predictability – and thus safety – governed the few possibilities for radical and innovative developments.

The regulations were developed in commissions consisting of members from different institutions. In its practice of decision-making by consensus thoroughly formed by all members with various interests, this operative site can also be considered a contact zone with its particular type of knowledge production.

Modelling a Scientific Construction: Science and Building Practice

The Construction of a Consistent Theoretical Basis

Apart from their involvement in technical reports or code committees, scientists emerged late as agent in the field of reinforced concrete. Since teachers and researchers at the polytechnic school were involved in projects before their academic career, often at different firms, there was a close interaction between building practice and academia. Especially in Switzerland and Germany, this relationship was growing at the beginning of the 20th century.

As shown earlier, Wilhelm Ritter (1847–1906) and François Schuele were the central figures with a stake in the formation of the new material from the science side. Schuele led many investigations into concrete as the director of the material lab, which closely collaborated with the material industry. Wilhelm Ritter was a professor at the polytechnic in Zürich and part of the first generation of engineers in Zürich. He studied at the young school from 1865 to 1868 in the recently finished main building. After returning from a railway project in Hungary, Ritter was assistant to Professor Karl Culmann (1870–1873) who primarily developed the theory and method of graphic statics. After Culmann's death, he became professor of graphic statics and bridge construction in 1983 and taught well-known Swiss engineers such as Robert Maillart (1872–1940) and Othmar Ammann (1879–1965).

In 1893, Ritter was invited by de Mollins (Hennebique) to carry out initial tests of reinforced concrete beams. Ritter published an article in 1899 discussing Hennebique's method. Going through the main aspects of the construction principles, he highlighted the most critical points and reviewed, like other experts at that time, Hennebique's simplified calculation. Ritter highlighted the differences in determining resistance, often overestimated, which was disconnected from the science of the strength of materials. As a consequence, he called for a comprehensive theory reflecting the hybrid elasticity of the compound. In his brief article, Ritter measured the defects of Hennebique's corporate design method, which was rarely grounded on a solid scientific foundation, neglecting basic material properties and constructive complications of the hybrid material. Ritter also proposed a more correct solution for the design method of T-beams which, as a mechanical and constructional aspect, exceeded the typical beam–plate relationship of existing materials and became a characteristic reinforced concrete feature. With his critical review on the general method, he contributed some of the fundamental aspects of the scientific theory of reinforced concrete. Elaborating on the structural role of the stirrups, for instance, he introduced the strut-and-tie model to describe the mechanical mechanisms of the shear effect (Ritter 1899) (Figure 1.4.8a). This method is closely linked to his education from Karl Culmann on graphic statics. Culmann, for instance, also used the method to demonstrate shear effects and explain the complicated buckling failure for iron bridges when wrought iron sheets were used for bridge girders (Culmann 1852: 165–167). Ritter successfully transferred the method to reinforced concrete, which helped to explicitly and precisely include stirrups in the overall play of forces. The method of graphic statics was also taught to Robert Maillart, who used it constantly in his professional design practice. In 1898, when Maillart proposed his concrete bridge for the Stauffacher Bridge, Ritter wrote a supportive technical report (Nievergelt 1995).

In Germany, the first steps in expatiating on the mechanical behaviour of the new material had been made a few years earlier. While the concrete pioneer Gustav Adolf Wayss invited officials from the local building authority to join his testing programme of reinforced concrete in Berlin, the civil engineer Mathias Koenen, who worked for the administration in Berlin, closely guided and supervised the load tests which aimed to establish trust and acceptance from the authorities and potential clients. Koenen published a first brief theory of reinforced concrete plates in 1886 and a more detailed inquiry in 1887 as part of an advertising booklet, edited and produced by Wayss (Koenen 1880; Wayss 1887). In the following year, he joined Gustav Adolf Wayss as a partner and technical director of the Beton- und Monierbau AG, taking over as a general director in 1891. He was also a founding member of the German Concrete Association. Koenen, who set up and followed the scientific basis of the new material, and coordinated and represented the building authorities while running his own small design consultancy before joining the large-scale building industry with Wayss' company, perfectly represents the close entanglement of the institutions involved in the establishment of reinforced concrete.

Another cross-border figure is the German engineer Emil Moersch (1872–1950), who continuously wandered between building practice and science before eventually taking on both roles simultaneously. Moersch first led the technical office of Wayss' company, by then known as Wayss & Freytag, until he took over Ritter's position at the polytechnic in Zürich in 1904. Still closely involved in the matters of his old company during his time in Zürich, Moersch decided to return to Germany in 1908 as a member of the board of directors at Wayss & Freytag. A few years later, he became a professor in Stuttgart (1916–1939). The close entanglement of industry and academia is clearly expressed in the collaboration of Moersch and his company on his standard textbook for reinforced concrete, which was republished and further developed in many editions. In 1902, Wayss & Freytag published *Der Betoneisenbau, seine Anwendung und Theorie*, for which Emil Moersch contributed the theoretical part, at that time with the company. Moersch published a revised edition of the book in 1906 during his time in Zürich, presenting a comprehensive and independent view of the subject in what can be considered the first academic textbook on reinforced concrete construction (Rauhut & Meyer 2018: 1, 106). He also picked up the graphic method of discussing shear stresses following Ritter's first steps, as can be seen in Figure 1.4.8b (Pogacnik 2018). Independently published in Stuttgart but still edited by Wayss & Freytag, the book was largely redeveloped by Moersch, implementing the Preliminary Guidelines for Reinforced Concrete Structures published in 1904 – to which he also contributed. For the third edition in 1908, Moersch was the only editor, with Wayss & Freytag being acknowledged as providing laboratory tests and construction references. During his time in Zürich, Moersch turned to Carl Bach, head of the Materials Testing Institute in Stuttgart, to undertake systematic laboratory tests which were financially supported by Wayss & Freytag. This close collaboration around Moersch in different roles is a vivid exemplification of the contact zones discussed earlier. Similar to the materials laboratory in Zürich, this zone allowed an essential production of highly particular and relevant knowledge that was scientifically grounded and designed for immediate application.

Construction as a Consequence of Institutional Interplay

A fascinating case of overlapping administration, science and design on the practice side in Switzerland can be found in Robert Maillart, already mentioned in the discussion of the Stauffacher Bridge. He started his career as a bridge builder using the new construction material, where he quickly demonstrated his unconventional way of thinking. In his design proposals and publications, he brings together a sound theoretical knowledge, a good understanding of construction processes and an extraordinary intuition of the material's behaviour. When Maillart proposed his concept of mushroom columns to support flat slabs avoiding downstand beams, there was no scientific theory explaining their structural behaviour. Recognizing that there was no way to capture the actual behaviour and stresses theoretically in the near future, Maillart decided to carry out his own load tests to measure performance. For that purpose, he carried out a series of loading tests by himself in 1908. Maillart built a flat slab on the yard of his own company in Zürich, spanning bidirectionally with three spans of 4 m each, and a thickness of just 8 cm. With the help of a portal crane, he loaded any of the 144 loading points in a grid of 25/25 cm and measured the resulting deflections (Figure 1.4.9). Based on the bending stiffness of a reinforced concrete beam model and the actual deflection of his physical model, Maillart developed an approximation procedure to determine the behaviour and limits of the slab.

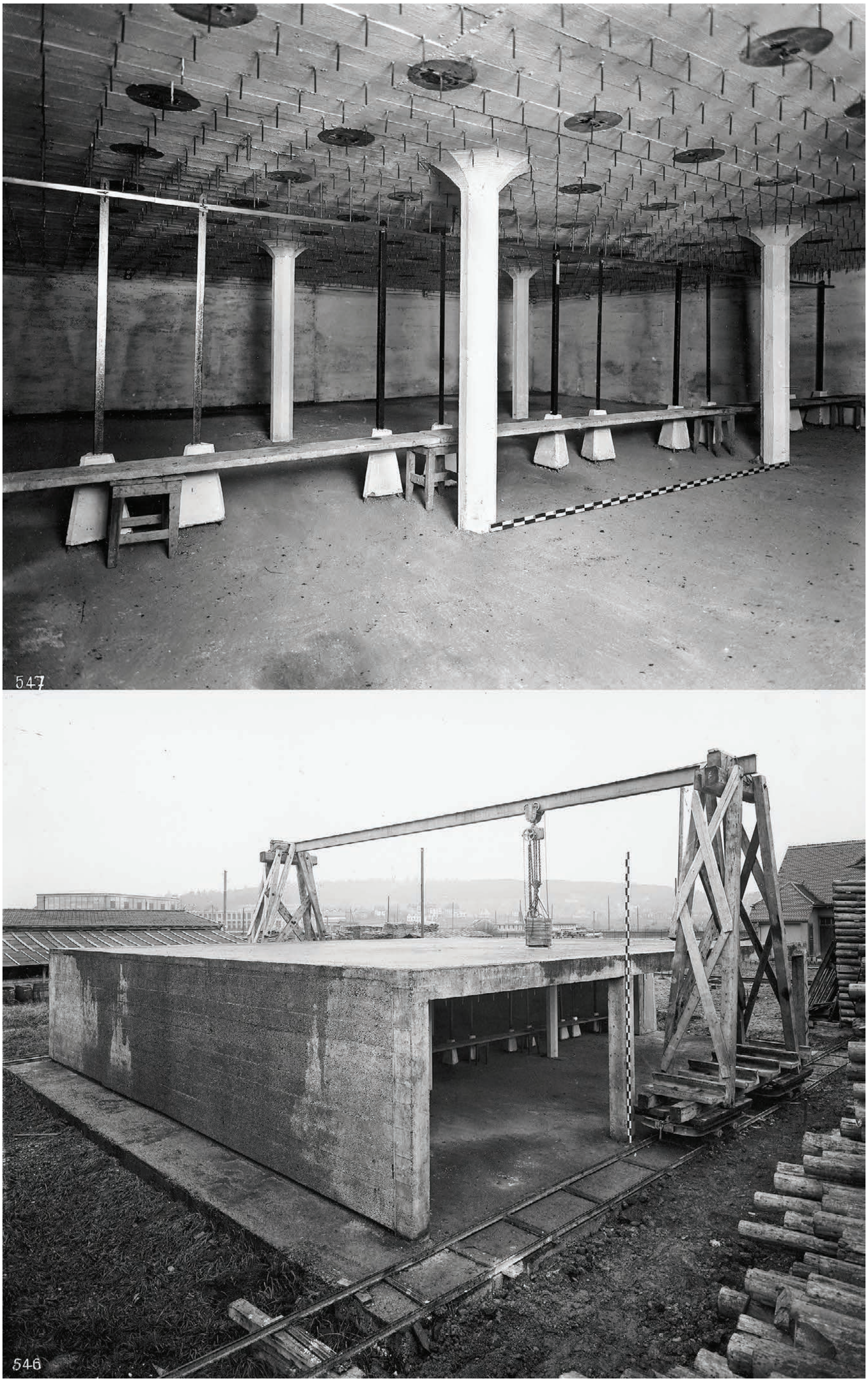


Figure 1.4.9 Loading tests by Robert Maillart in Zürich in 1908: structural slab with supports and measuring grid (top) and the loading portal crane (bottom).

Source: ETH-Bibliothek Zürich, Bildarchiv.

One year later, in 1909, Maillart patented his beamless slab method in Switzerland. Based on his experiments and calculations, he was able to build numerous mushroom column structures in Switzerland and abroad. Just like the successful parallel introduction of mushroom columns in the USA, his method provided a cheaper way of slab construction and was soon well known in Europe (Thuy & Rinke 2018: 1276).

The mushroom column can be considered as the first genuine concrete construction since it did not reproduce constructional forms of other material systems – such as steel or timber beams – to form a structural deck (Kierdorf 2006: 1793). As this new constructional element exceeded the existing practice of reinforced concrete design and production, its introduction saw conflicts with the existing regulations recently implemented and revealed their underlying philosophy through the powerful institutions involved. While in Switzerland, the mushroom column was successfully introduced and quickly became a standard element in construction, it found almost no application in Germany at that time, although there was a technological and constructional knowledge and scientific basis in Germany that would potentially allow it. The Swiss concrete code was based on a philosophy of empiricism, giving opportunities to those who could practically prove their innovative concepts through experiments or by developing alternative theoretical approaches, establishing the ground for Maillart to question existing practices and push for new ways in concrete technology (Maillart 1912, 1926). In Germany, however, the code was based on a philosophy of rational theory that gave the role of formulating the basic rules and red lines to the very recently established technical sciences at the polytechnics. Since there was no theoretical basis for the design of flat slabs – that is surface structures, their punctual support and not to mention the spatial stress distribution in between – mushroom columns were practically impossible to calculate and thus to build. Only after their theoretical modelling in 1920 were mushroom columns integrated into the code in 1925 to finally become a standard part of the constructional practice of reinforced concrete (Lewe 1920, 1926).

Innovation as an Entanglement of Agents

The case of the mushroom column is representative of the various consequences of the interconnection of institutions leading to a push or a limitation of technologies. Moreover, this study shows that, although there were significant individuals who exceptionally made contributions to the development and implementation of the new construction material, its technical success and broad diffusion was not due to any one of them alone but their interaction together. The complex interlinking of institutions, each with different backgrounds, internal structures and interests, along with their professional and social history, stimulated what would preferably be swift application in the building industry. There were various paths to do so. The Swiss corporatism enabled a considerable portion of industrial influence throughout all levels of technological implementation, whether at the administrative level in new regulations or the scientific level in testing and codifying materials in the laboratory.

As in the case of any other modern technology, the development of reinforced concrete did not take place in the form of collaboration only. This study of institutional relationships has shown that the crucial fields of research and development lay somewhere in between. The cases of code development and laboratory tests highlight the form of contact zones where representatives of different institutions came together to develop not only new technologies, knowledge or rules but also particular professional cultures and practices. In Switzerland and Germany, where the industry (material and building industry), administration (authorities and representative bodies) and science (within the industry and in academia) were simultaneously finding their shape and roles, the professional development of concrete and reinforced concrete displayed mechanisms of successful and long-term implementation based on the basis of lively and multilevel entanglement of various contributors.

Notes

1 Parts of this chapter are also covered in the German publication M. Rinke, “Konstruktion des Limits – Frühe Normen im Stahlbetonbau in der Schweiz und Deutschland”, in Werner Lorenz & Roland May (eds), *Bauen am Limit*, series, Kulturerbe Konstruktion, Basel: Birkhäuser, 2023 (in press).
2 For example Giedeon (1928) or Hilbersheimer (1928).
3 For example Mollins (1893), Mollins (1901) and Ritter (1899).
4 In 1895, there were already 26 Swiss factories running with a yearly production rate of 3,000 to 30,000 tonnes each. A few years later in 1910, the Swiss cement manufacturers founded a national union, the EG Portland.
5 The guiding philosophies and regulated aspects of the early concrete codes in Europe are discussed in Van De Voorde et al. (2017).
6 The building authority from Basel consulted the German cities Dresden, Düsseldorf, Frankfurt am Main, Hamburg and Karlsruhe on their regulations on reinforced concrete and asked the commission of experts (Schüle, Geiser, Ritter) if systems of constructional practice could be allowed and how extensive they should be, that is for reinforced concrete systems: System Koenen, System Hennebique, System Siegwart and for slab construction: System Münch and System Schürmann (SBZ 1904).
7 For general Hennebique construction: submission of plans of the Hennebique structure and statical calculation, material and origin, mixture and compression strength, detailed programme for execution, compression tests with test cubes, certificates of experience for foreman or site supervisor, for approval with authority – but this would be a lot of effort for administration with highly qualified and trained staff or expertise from a third party, so only recommended for special cases. For normal cases, standard checks were recommended, the degree of safety was specified using allowable limits for stresses, cement quality ideally standardized and restricted to registered Swiss factories, timing and sequence to retract the formwork, subsequent checking of concrete surfaces for cracks. General rules for calculation and design: no tension in the concrete, eccentrically loaded columns, joints for shrinkage effects, not using concrete for harsh weather conditions.
8 Such as concrete cover (1 cm!) and iron bars anchoring or checking aspects.
9 With a German Committee for Structural Concrete in 1907 issuing regulations nationwide.

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Chapter 1.5

The First Patents for Reinforced Concrete

The Origins of the 20th-Century Construction Revolution in Spain

Francisco Domouso de Alba

The Invention of Reinforced Concrete: Patents

As an invention, reinforced concrete came into being in the 19th century, and inventions were the most important reason for the rise of patents during the Second Industrial Revolution. It is not possible to pinpoint a single place or country of origin for reinforced concrete; neither can its invention be attributed to just a few figures (Collins 1995: 9).[1] Given that it was developed in parallel in the developed European nations and in the USA during the 19th century, it is perhaps one of the inventions discovered by most people simultaneously in the history of construction.

Intuition in construction had a major role in the invention of reinforced concrete. Simultaneous work on two materials with complementary resistant characteristics is nothing new in the history of construction. Traditionally, steel has frequently been employed to reinforce other materials such as wood, ceramic or stone.[2] In the 18th century, it was common for steel to be used to pin together complex sections of ashlars, above all in lintels, arches and flat vaults, functioning not only as an interconnecting element but also to support the tensile forces generated in the structure they formed part of.

The first structures made of reinforced concrete took the form of slim walls in various objects, such as boats (Figure 1.5.1), jardinières or water cisterns. Creating continuous, resistant panels of cement (or some other material) had been an aspiration of builders and engineers throughout history, and intuition led them to introduce isotropic grids of steel bars into a cement mass to achieve a continuous and resistant plane of cement that could withstand the forces that would act on the structure. An example of this is the patent registered by Joseph-Louis Lambot (1814–1887) in 1855 – possibly the first patent in the world of reinforced concrete[3] – or the first patents registered by Joseph Monier (1823–1906) in 1867 and subsequent years.

Observing the behaviour of the combination of cement and steel led inventors to conclude that the adherence between the two materials was good and that, used together, the materials were capable of withstanding the deformations that occurred when the reinforced material was subjected to different structural stresses. Some engineers understood that the combination of cement and metal was able to withstand bending stress without deformation since the concrete resisted the forces of compression while the metal resisted tensile forces. For the first time in the history of construction, technicians could control the structural response of the material according to their working hypotheses and the arrangement of the reinforcing framework within the concrete mass.

Patents were very important during the early development of reinforced concrete for two fundamental reasons: the product and the business. First, patents offered an end product that worked.

DOI: 10.1201/9781003368656-7

Figure 1.5.1 "Un bateau en ciment armé agé de 54 ans. Vue du lac de Miraval (A boat in reinforced cement 54 years old. View taken from Miraval Lake)".

Source: Le Betón Armé, 1902.

Early structures or applications of reinforced concrete were not calculated or constructed following regulations; rather, they were purchased. The results of the purchase generally met the demands of its end use. Patents sold structural systems whose functioning was corroborated by experience but little or no scientific backup – or at least, so it seemed.

Meanwhile, business was the main reason for the existence of patents.[4] For the first time in building history, the invention of a material allowed its users – and there were many – to earn large amounts of money from it. And this was made possible because the Second Industrial Revolution established the legal bases of protection of intellectual property, and reinforced concrete needed to be invented. Expanding cities and the development of large-scale infrastructures at the end of the 19th century required a material like reinforced concrete. The market open to the new material was almost unlimited. From this moment on, reinforced concrete would be the most widespread structural material in use, applied to buildings and objects of all kinds.

In a short space of time, businesspeople, inventors, builders, architects and engineers identified an opportunity for profit by selling partial or complete structural systems made of reinforced concrete whose internal workings were only known to – or intuited by – their inventors. Patents were used to cover the trial-and-error costs of a material which was supported by little theoretical evidence in its early phases. But they also provided a means of marketing the material by demonstrating the benefits of reinforced concrete through a wide range of testing processes involving impossible loads, fire resistance and so on. These tests, which were abundantly documented in images at the time (photographs and plans), and certified by scientists, architects and engineers associated (or not) with the patent, were the best business card for attracting new customers.

Between the end of the 19th century and the start of the 20th century, reinforced concrete transitioned from a patented product to a technique. This was the last stage of the invention of reinforced concrete. The twilight years of patents had begun. The patents of Monier and François Hennebique (1842–1921) entered the public domain in 1904, making it easier for any Spanish technician or company to employ the two systems, which were the most popular and advanced techniques.[5]

This change was accompanied by an increasingly broad and reliable scientific and theoretical development in the form of treatises, manuals and the first specific regulations at the state level. Reinforced concrete progressed from being a patented product to a material available to any engineer, architect or builder.

Reinforced Concrete in Spain During the Period 1884–1906

Spain was two decades behind France and Germany in introducing reinforced concrete techniques. During the last years of the 19th century and the first five years of the 20th century, the business, construction and theoretical foundations were laid in Spain that would allow the subsequent development of reinforced concrete and within just six years, a school of construction engineers and architects was producing first-rate structures in that material.

Construction techniques evolve and develop in line with the needs of society, and the need for reinforced concrete in Spain stemmed from the country's historical, economic and territorial circumstances. Until the early 20th century, construction in reinforced concrete in the country was practically non-existent. Between 1900 and 1906, Spain made up for lost time, catching up with the rest of Europe. And reinforced concrete patents played a vital role in this late development. The first patents registered for reinforced concrete in Spain made it possible to learn and develop construction processes from other countries with more experience in the use of the material,[6] and in particular the French influence during the early years of the use of reinforced concrete in Spain must be highlighted. The *Revista de Obras Públicas*, a landmark journal in the dissemination of building science at the end of the 19th century (and still published today) reported on the articles, works and experiments emanating from France to the benefit of Spanish engineers.

In 1884, the first patent for reinforced concrete – Monier's French patent – was registered in Spain. Between 1884 and 1899, only minor works were carried out in the country using the material, such as the open cistern in Puigverd de Lleida (1893), built by the engineer Francesc Macià (1859–1933) using the Monier patent (Figure 1.5.2). The cistern is still in use today. It was the first structure in reinforced concrete on record in Spain, albeit a minor work both in terms of its structure and the complexity of its execution. The type of deposit with slim walls of reinforced concrete that form part of the Monier system became common in subsequent years. The company Lecanda Macià produced many minor, small-scale structures, such as water tanks and objects made of reinforced concrete.[7]

During the last decades of the 19th century, the situation in Europe was very different. Constructions in reinforced concrete – and in particular those based on Monier patents – had proliferated, and by 1890 there was advanced knowledge of the material, its structural behaviour and

Figure 1.5.2 Open cistern in Puigverd de Lleida. Design: Francesc Macià. 1893.
Source: CEDEX-CEHOPU, available at www.cehopu.cedex.es/hormigon/ (accessed 20 November 2022).

the building and construction techniques it required. The following examples illustrate European mastery of reinforced concrete at this point:

- 1890: the reinforced concrete bridge at Wildegg, Switzerland, built by the Monier construction company. Despite the geometric simplicity of the bridge, its construction required complex formwork and trusses to cross the riverbed. The slenderness of the bridge's keystone and its important span demonstrate the confidence in calculating the structure's dimensions of the technicians that designed and executed the plans (Figure 1.5.3);
- 1890: reinforced concrete pedestrian bridge built for the Expo in Bremen, Germany. A 40-metre arch designed by the engineer Mathias Koenen (1849–1924), technical director of the Wayss company. Executed by the Monier construction company. Mathias Koenen and Gustav Adolf Wayss (1851–1917) registered a patent in Spain in 1892, which essentially summed up the system used to create the pedestrian bridge (Figure 1.5.4);
- 1900: Paris factory ceiling and roof by Paul Cottancin (1865–), who registered a patent for his system in Spain in 1891 (Figure 1.5.5).

These examples have been chosen for the advances they involved in technical and construction terms. From a structural point of view, they understood the behaviour of reinforced concrete arches of a certain section and introduced a daring roof structure with a touch of spacecraft about it. It was also necessary to employ complex formwork and thick trusses to successfully execute such designs.

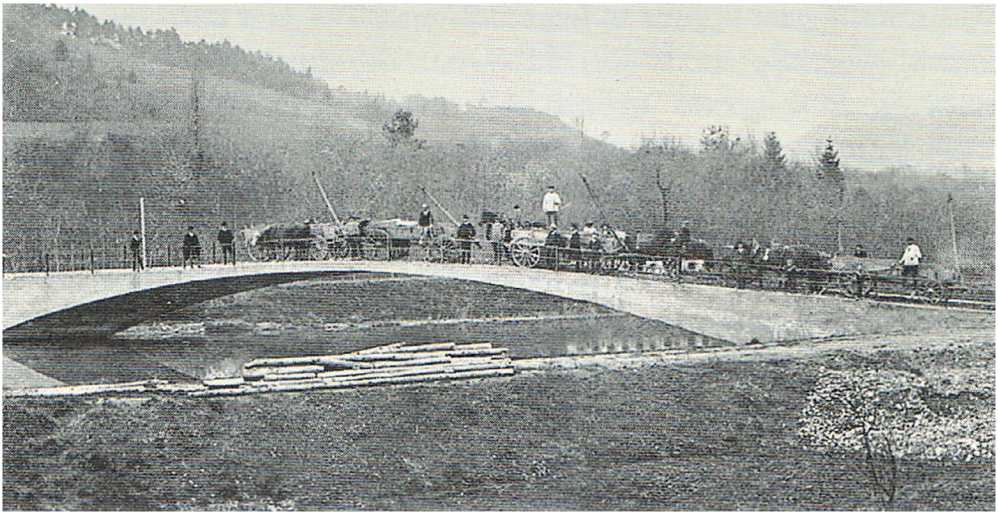

Figure 1.5.3 Reinforced concrete bridge at Wildegg, Switzerland, by an unknown designer, 1890.

Source: Bosc et al. (2001: 114).

Figure 1.5.4 Reinforced concrete pedestrian bridge built for the Expo in Bremen, Germany. Design: Mathias Koenen, 1890.

Source: Bosc et al. (2001: 116).

Figure 1.5.5 Factory ceiling, Paris. Design: Cottancin, 1900.
Source: Berger and Guillerme (1902: 845).

New types of reinforced concrete construction would not be introduced in Spain until 1898, when works with some degree of structural complexity began to be executed. Between 1898 and 1899, José Eugenio Ribera (1864–1936) built the slabs to be used for a new prison in Oviedo in reinforced concrete using the Hennebique system.[8] The solid concrete slabs of reinforced concrete measuring 3.50 × 2.60 m were supported around the whole perimeter by brick load-bearing walls. The construction was preceded by a vast technical and advertising display, well documented by the journal *Revista de Obras Públicas*. A year later, Ribera built a cistern in Llanes, also using the Hennebique system, and with a technical complexity similar to that of the cisterns constructed by Macià under the Monier patent.

In 1899, the first building in reinforced concrete was erected in Spain: the Viuda e Hijos company's flour mill in Ayala, Badajoz (Figure 1.5.6), another Ribera design using the Hennebique patent (Ribera 1902). Pillars, beams, girders and reinforced slabs shaped this first whole structure to be completed in reinforced concrete. The complete application of the Hennebique system was patented in Spain in 1898. Immediately after, between September 1899 and May 1900, the flour mill known as *La Ceres* was constructed in Bilbao (Figure 1.5.7). It had a considerably complex geometric structure due to the shape of the plot it stood on – and its construction was of equal complexity. The design was for a complete reinforced concrete structure following the Hennebique system (Rosell & Cárcamo 1994), while the work itself was entrusted to the civil engineers Ramón Grotta (1868–1900) and Gabriel Rebollo (1871–1941).

These works are examples of the Spanish capacity of construction in reinforced concrete in 1900, but we must note that all the technology employed (both in design and execution) was imported from France.[9] Nevertheless, such works initiated a boom in reinforced concrete in the country. And as of 1900, constructions in that material began to be plentiful in Spain, and their types and structural designs gradually became more complex (Figure 1.5.8 and Figure 1.5.9). The Palacio Valdés theatre in Avilés, Asturias, initiated in 1900, the work of the engineer Eugenio Ribera and the architect Manuel del Busto (1874–1948) (Figure 1.5.10), can be considered the starting point for this brief five-year period leading up to 1906 in which Spain caught up with the rest of Europe in terms of its works in reinforced concrete. This work paved the way for reinforced concrete in Spain, with building types a far cry from the usual industrial and civil engineering models. It was the first complete structure for a public building rendered in reinforced concrete.

The three key figures who introduced reinforced concrete in Spain were the engineers Eugenio Ribera, Juan Manuel de Zafra and François Hennebique.

José Eugenio Ribera was born in Lisbon, the son of the civil engineer Pere Ribera i Griñó (–1908). He completed his own civil engineering degree in 1887. He was a self-confessed nonconformist: “I admit that during my years as a student at the unseemly college on calle del Turco, I studied little, and learned even less”. His professional career can be divided into three distinct phases (Machimbarrena 1936): the 12 years that he worked as an engineer in the service of the State in the province of Oviedo; the period where he was the project supervisor directing the construction companies he had founded; and a final phase (and without having abandoned his management activities) in which he worked as a professor. He began his career as a builder

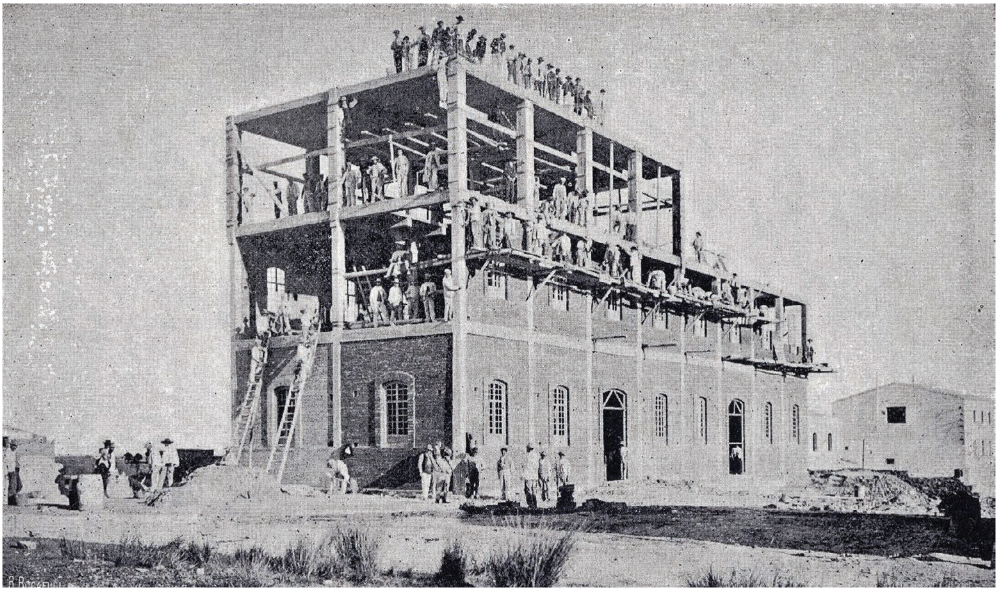

Figure 1.5.6 The *Viuda e Hijos* flour mill in Ayala, Badajoz, 1899. Design: Ribera.

Source: Ribera (1902: 35).

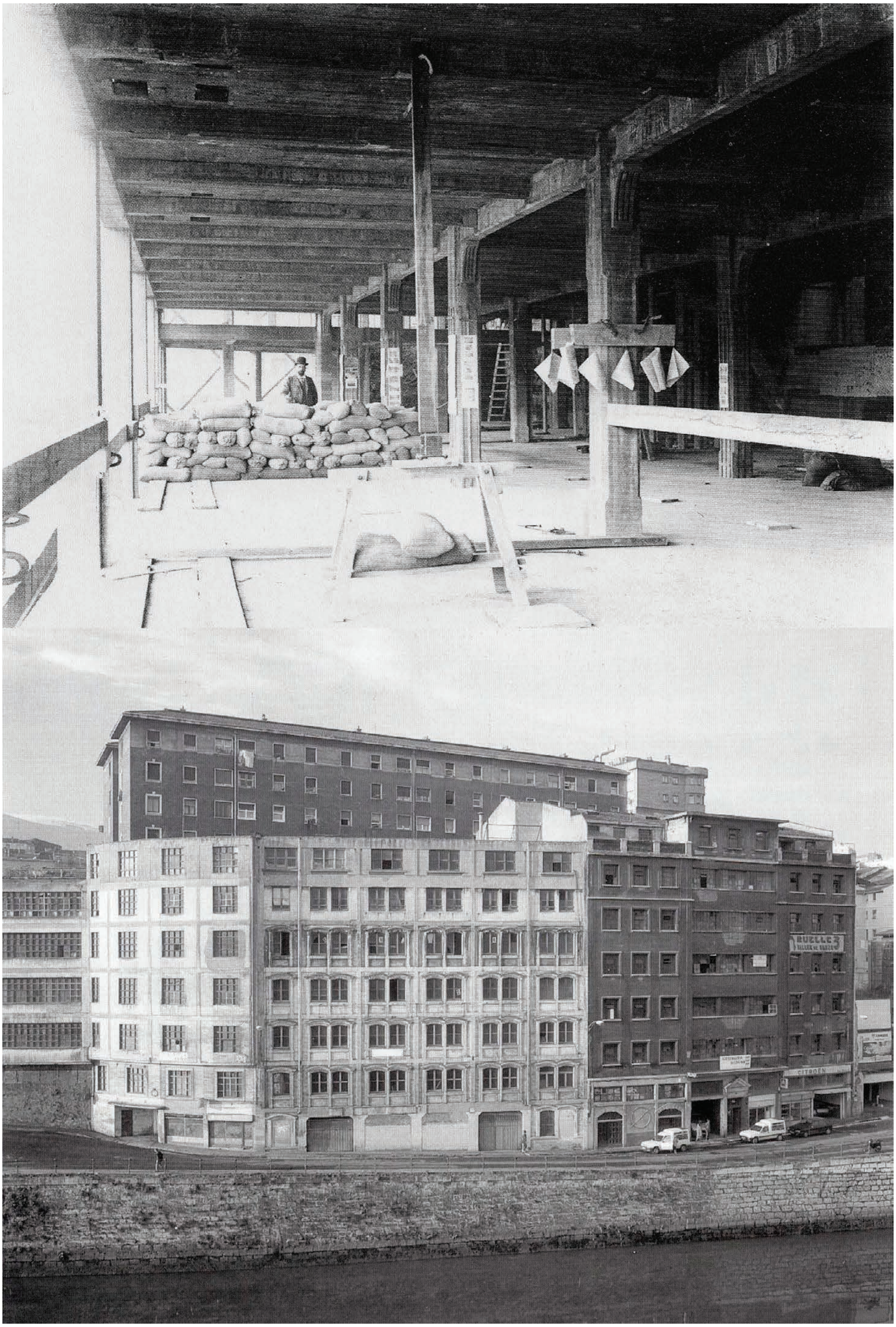

Figure 1.5.7 *La Ceres* flour mill, Bilbao, under construction (top) and after completion of work (bottom). Design: Hennebique with Ramón Grotta and Gabriel Rebollo, 1899–1900.

Source: Rosell and Cárcamo (1994: 111, 150).

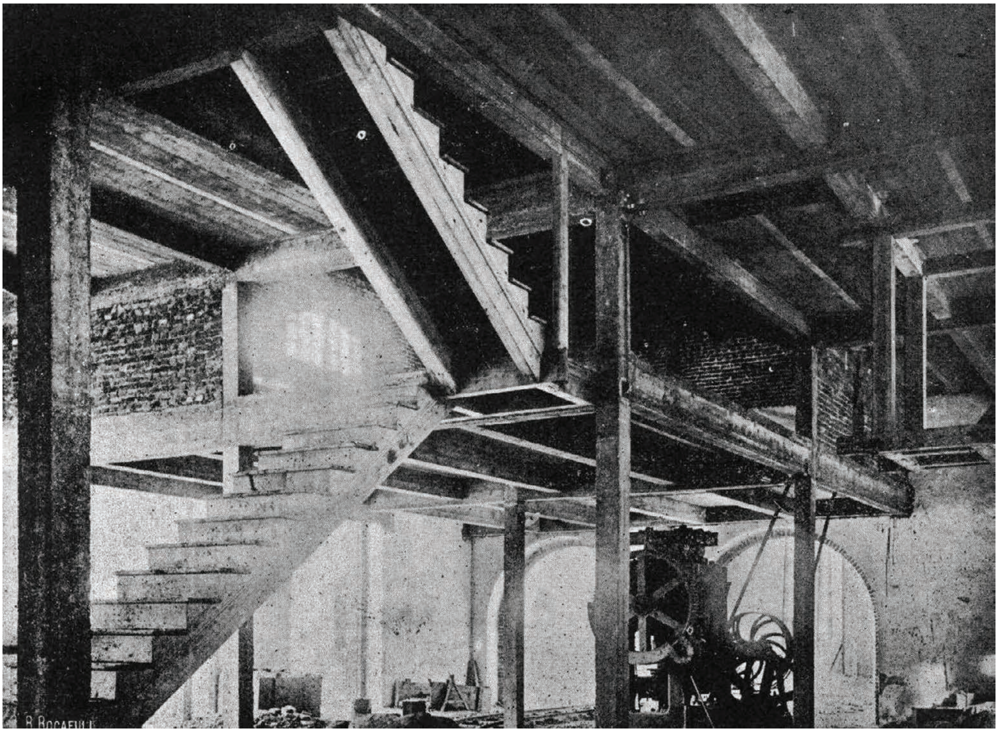

Figure 1.5.8 Detail of the stairway at the Portland cement factory in Tudela Veguín. Design: Ribera, 1901.

Source: Ribera (1902: 34).

Figure 1.5.9 *La Peña* Bridge over the River Nervión, Bilbao. Design: Rebollo and Hennebique, 1902.

Source: http://historiastren.blogspot.com.es (accessed 20 November 2022).

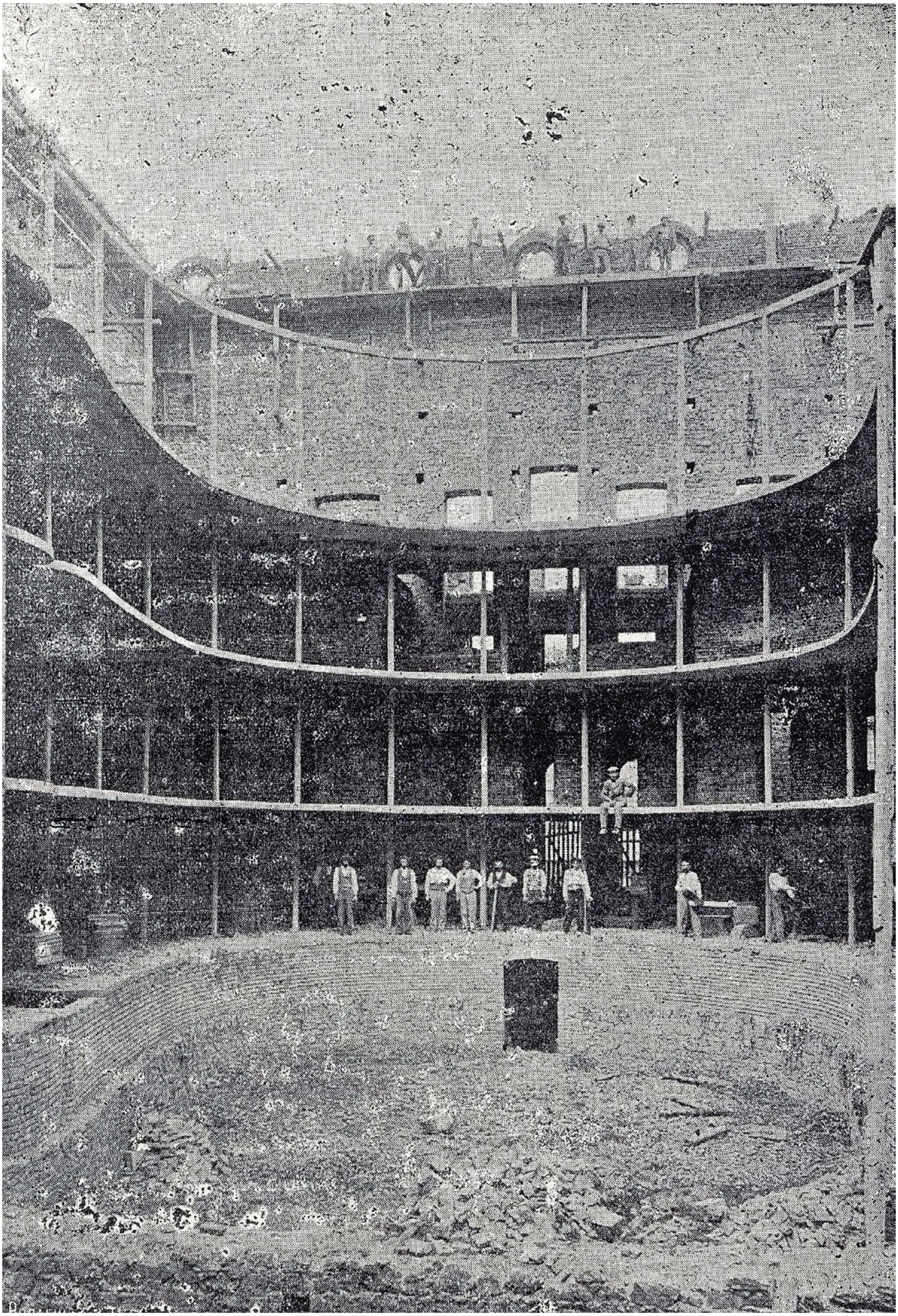

Figure 1.5.10 Interior view of the Avilés Theatre. Design: Ribera and del Busto, 1901.
Source: Ribera (1902: 49).

using steel as a structural element of the public works he was involved in. As an engineer working for the Spanish government on public works in Asturias, in 1899, Eugenio Ribera founded the first licensed firm using the Hennebique system in Spain. Following a visit to Geneva where he observed the construction of the reinforced concrete arches of the Coulouvrenière Bridge, and the concrete slabs of the new post office building in Lausanne, he wrote: "I admit to being astonished by these kinds of buildings, which broke away from all the traditions, to some extent old-fashioned, which we tend to adhere to in our schools". In 1918, he started working as a professor at Madrid's Escuela de Caminos (School of Civil Engineering). There he taught Eduardo Torroja (1899–1961), the future great Spanish pioneer in the design of reinforced concrete shells.

Hennebique took a personal interest in Ribera and the potential he offered for introducing Hennebique's methods in Spain, since Ribera was a public officer and already an important figure in his own right; therefore he visited him in Spain (Delhumeau 1999: 125). In his capacity as a state engineer of public works in Asturias, Ribera sent preliminary designs to Hennebique's Paris offices to be examined and improved. Ribera and Hennebique had a fruitful relationship between 1895 and 1899, which gave rise to modest but varied works. During this period, various new construction types in reinforced concrete were introduced to Spain: straight road bridges, bridge decks, slabs such as those used in the prison at Oviedo, Asturias in 1898 and water tanks and cisterns like the one in Llanes. Ribera executed all of these works as a state engineer. In September 1899, Ribera was officially granted a concession of the Hennebique firm in Oviedo; he was also a member of the first editorial board of the journal *Le Béton Armé*, the "body disseminating the authorized dealers of the Hennebique system".

Juan Manuel de Zafra was born in Huelva on 24 August 1869 and died in Madrid on 26 March 1923. His professional career was tied in with the development of reinforced concrete from very early on. His first work in reinforced concrete was a mining jetty in San Juan de Aznalfarache, Seville (Figure 1.5.11), built in 1904 for the company Minas de Cala, which mined iron deposits in Huelva. An engineer with a vast and rigorous scientific training, he applied his solid knowledge of mechanics when creating reinforced concrete structures.

Zafra joined the teaching staff at the Special School of the Corps of Civil, Canal and Port Engineers, imparting the class on "Constructions in Reinforced Concrete, Ports and Maritime Signals", which was the first module in the subject "Constructions in Reinforced Concrete and Ports". The course became the first undergraduate degree in Spain in the discipline, running for the first time during the academic year 1910–1911. In 1911, Zafra published the book *Construcciones de hormigón armado* (*Constructions in Reinforced Concrete*), the first scientific treatise on reinforced concrete by a Spanish author, which he would later build on with the book considered to be his masterpiece (in the words of the engineer Enrique Colás), *Cálculo de estructuras* (*The Calculation of Structures*) published in 1915–1916, in which the author applied theories of elastic strain to structural calculations. Zafra also wrote various articles disseminating and developing these theories.

In 1906, construction in reinforced concrete had reached a level in Spain, which was similar to the rest of Europe. This rapid development was made possible by the fundamental role of patents as follows[10]:

- in Spain, the main European systems of reinforced concrete were patented during the period 1884–1902: the best technology and knowledge on reinforced concrete reached Spain before large-scale, complex works had been undertaken;
- the exploitation of reinforced concrete patents gave rise to Spain's modern construction companies;
- reinforced concrete patents offered substantial advantages to the construction sector: a selection of the patents registered in Spain during the period in question provided the first-rate

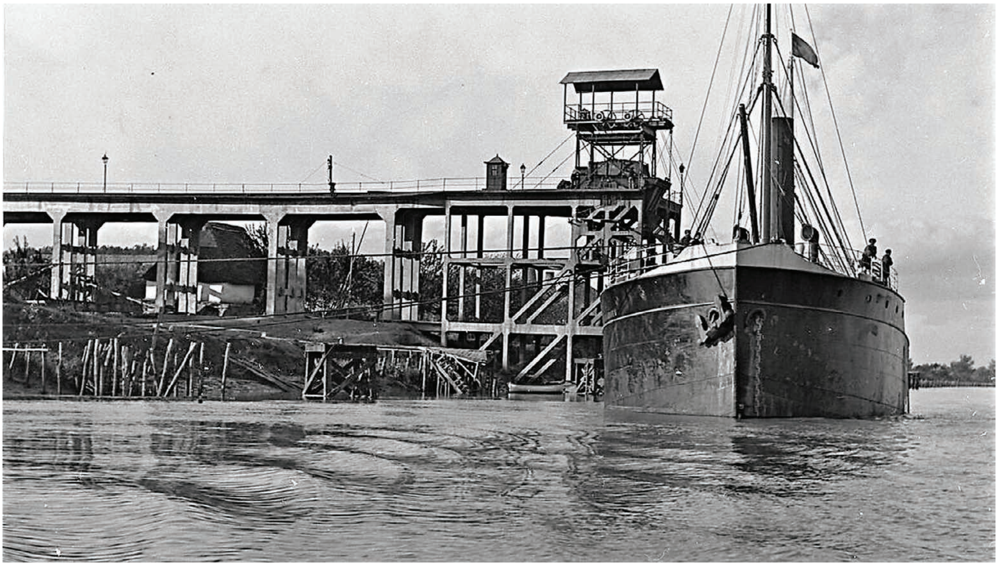

Figure 1.5.11 The first jetty built to serve the Cala mines, San Juan de Aznalfarache, Seville, 1904. Design: Juan Manuel de Zafra. Image author: Charles Edward Rowcroft.

Source: A. Serrano's collection.

building know-how required for the swift development of reinforced concrete during the period 1901–1906.

The First Reinforced Concrete Patents in Spain: 1884–1906

During the period 1884–1906, some 114 reinforced concrete patents were registered in Spain.

- Number of foreign patents: 59 (51.8%)
- Number of Spanish patents: 55 (48.2%)
- Number of patents licensed: 48 (42.1%)
- Total number of foreign patents licensed: 29 of 48 (60.4%)
- Reinforced concrete systems: 32
- Applications (reinforced concrete replacing another material): 63
- Machines whose purpose was the manufacture of reinforced concrete applications or improvement of components: 9
- Procedures or construction methods using reinforced concrete: 10

The origins and sequence of events in the implementation of the patents registered in Spain during the period 1884–1906 can be schematically represented as follows (Figure 1.5.12 and 5.13):

Analysing the data by sub-periods, the results are as follows:

During the period 1884–1900,

- Number of patents registered: 29 (25.4%)
- Percentage of which were foreign patents: 82.7%

- Percentage of which were Spanish patents: 17.3%
- Percentage of patents licensed: 58.6%
- Percentage of foreign patents licensed: 88.3%

During the period 1901–1906,

- Number of patents registered: 85 (74.6%)
- Percentage of which were foreign patents: 41.2%
- Percentage of which were Spanish patents: 58.8%
- Percentage of patents licensed: 36.4%
- Percentage of foreign patents licensed: 45.2%

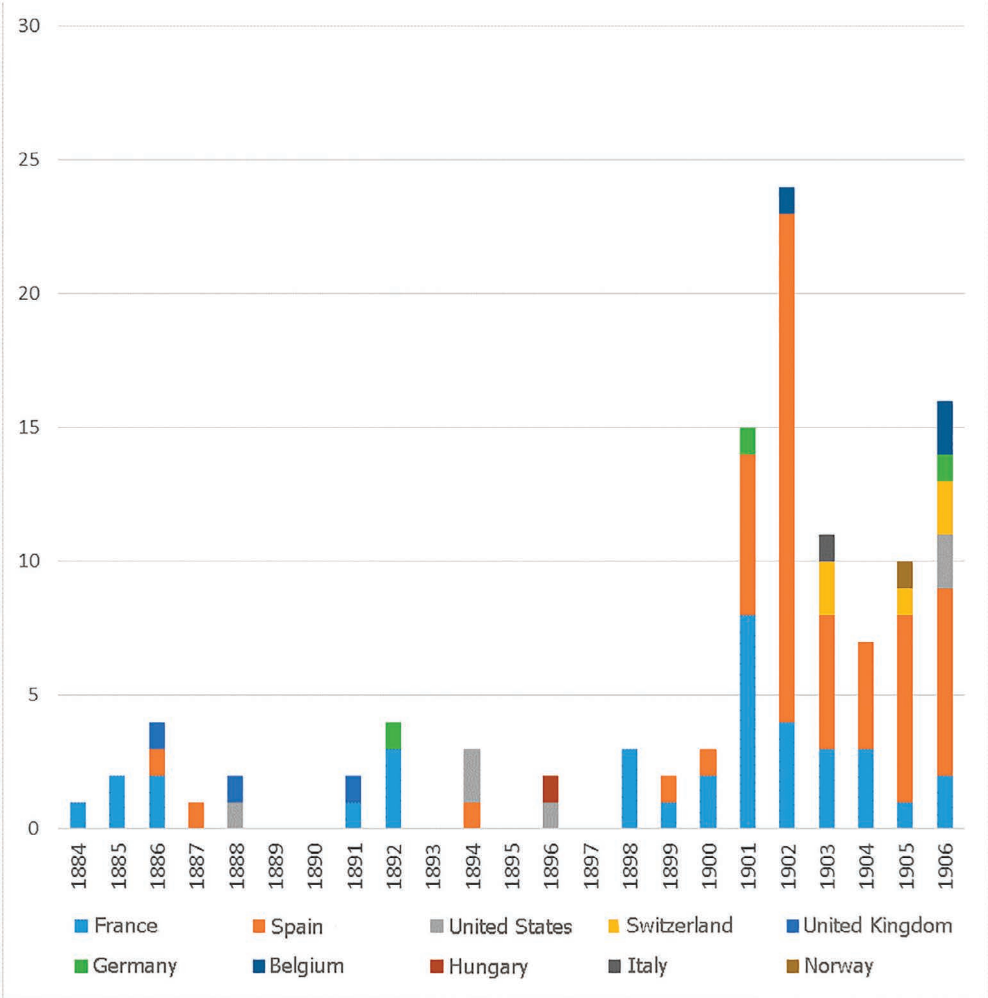

Figure 1.5.12 Ratio of the number of foreign patents registered in Spain by year and country of origin for the period 1884–1906.

Source: The author's own data.

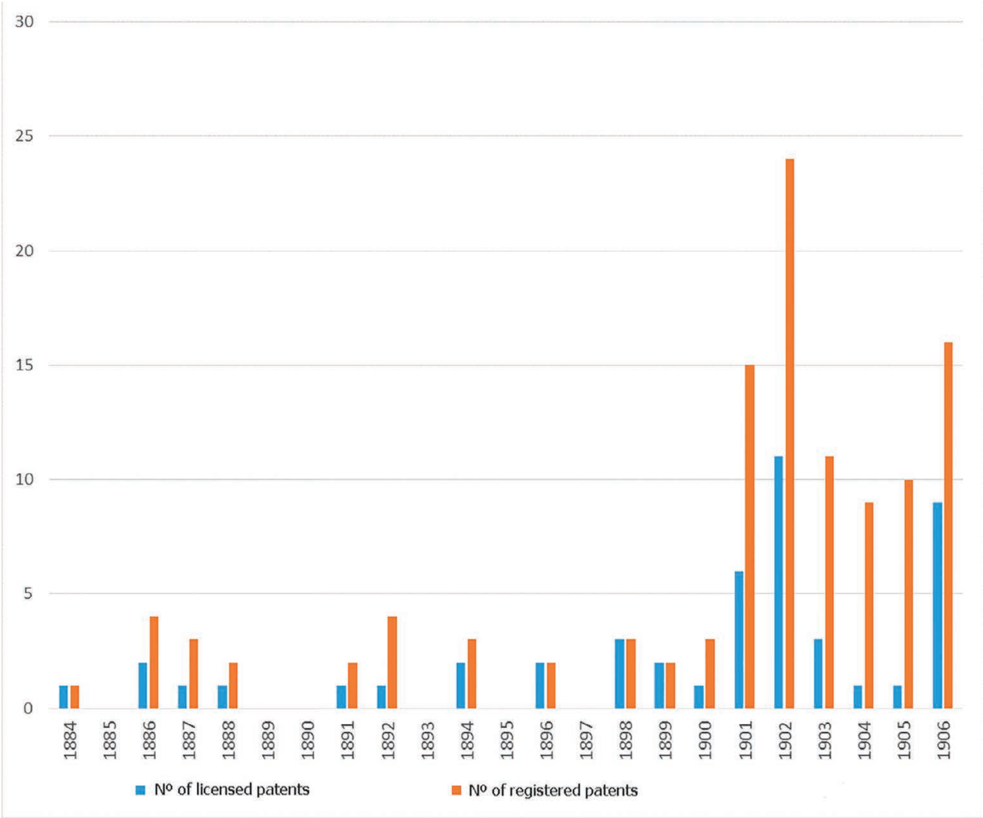

Figure 1.5.13 Annual number of patents implemented compared to the number of patents registered in Spain related to reinforced concrete for the period 1884–1906.

Source: The author's own data.

During the period 1884–1900, some 82.7% of reinforced concrete patents registered in Spain were foreign patents. During the period 1901–1906, Spanish practitioners and builders incorporated reinforced concrete technologies into the construction sector in general. As of 1902, Spanish patents became more common than foreign ones: during this period, a total of 41.2% of reinforced concrete patents registered in Spain were foreign compared with 82.7% in the previous period, 1884–1900. In addition, the licensing of patents shows that the Spanish construction sector incorporated the technology that had been tested at the international level.

Of the 114 patents for reinforced concrete registered in Spain between 1884 and 1906, some 42.1% were put to practical use. It is significant to note that some 60.4% of these were foreign patents. The exploitation of a patent entails the real transfer of technological know-how to the construction sector.[11]

The Landmark Foreign Systems Patented in Spain

Of the 29 patents related to reinforced concrete registered in Spain between 1884 and 1900, some 24 were foreign, mainly originating in France. The manuals by Berger and Guillerme (1902) and Christophe (1902) are particularly relevant when identifying these patents. Both publications were landmark references at the time in France and Central Europe, as well as in Spain, although they happened to coincide very little on the reinforced concrete systems they documented. Ten of the twelve systems patented in Spain were licensed. Moreover, the time that passed between the original patent and its registration in Spain was short: in the case of five of the patents, this period was under a year; in the case of another four, it was less than two years. The others reached Spain six or seven years after being registered for the first time.

This transfer of the best construction technology of the age allowed a rapid development of reinforced concrete in Spain between 1901 and 1906, since the patents contributed experience already tried and tested in other countries. Such prior experience avoided the need for the laborious process of trial and error that usually characterizes new techniques. This provides further support for the hypothesis that patents meant that the most advanced applied knowledge of reinforced concrete was available to be used, despite the scarcity of construction works applying them.

The most important patentees for reinforced concrete systems in Spain during the period 1884–1902 were:

- Bordenave, Jean: 1887 patent (Figure 1.5.14)
- Considère, Armand Gabriel (1841–1914): 1903 patent (Figure 1.5.15)
- Cottancin, Paul: 1891 patent (Figure 1.5.16)
- Golding, John French: 1894 patent
- Habrich, Franz: 1901 patent (Figure 1.5.17)
- Hennebique, François: 1892 patent; 1898 patent (Figure 1.5.18)
- Koenen, Mathias/Wayss, Gustav Adolf: 1892 patent (Figure 1.5.19)
- Mátrai, Alexander: 1896 patent (Figure 1.5.20)
- Monier, Joseph: 1884 patent; 1886 patent (Figure 1.5.21)
- Wilson, David: 1886 patent.

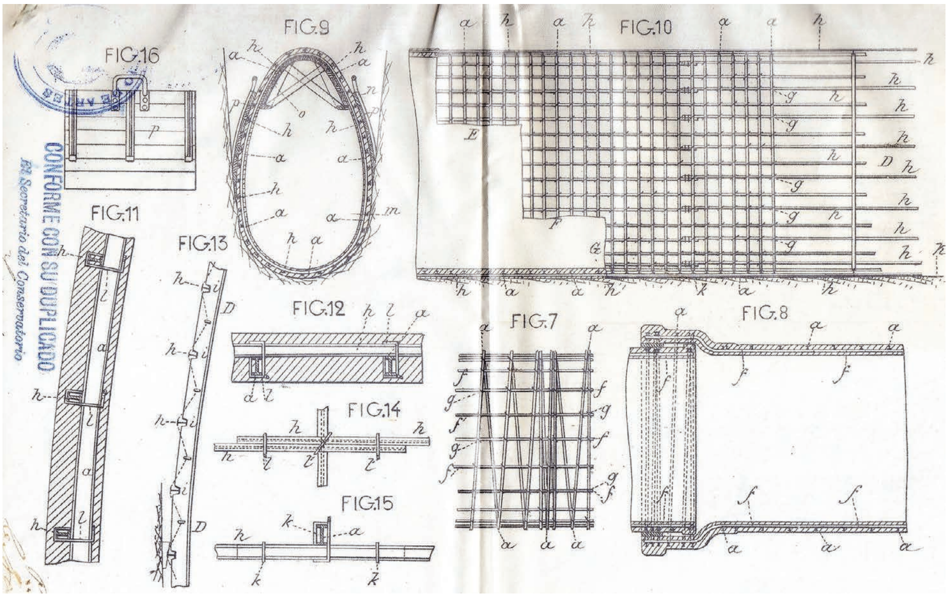

Figure 1.5.14 Bordenave, Spanish patent no. 6.850, 1887.

Source: Spanish Patent and Trademark Offices, Historical Archives, Madrid.

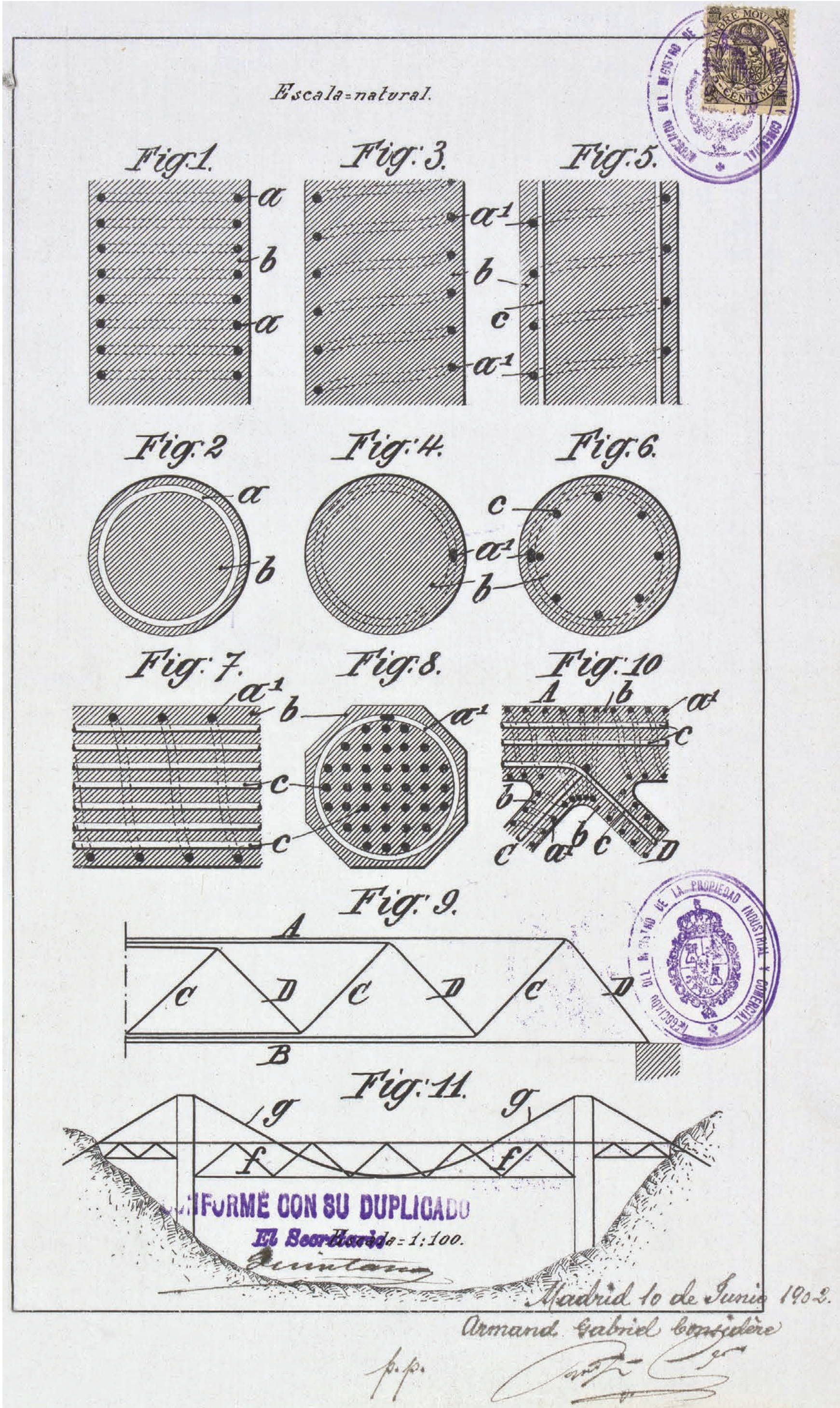

Figure 1.5.15 Considère, Spanish patent no. 29.940, 1903.

Source: Spanish Patent and Trademark Offices, Historical Archives, Madrid.

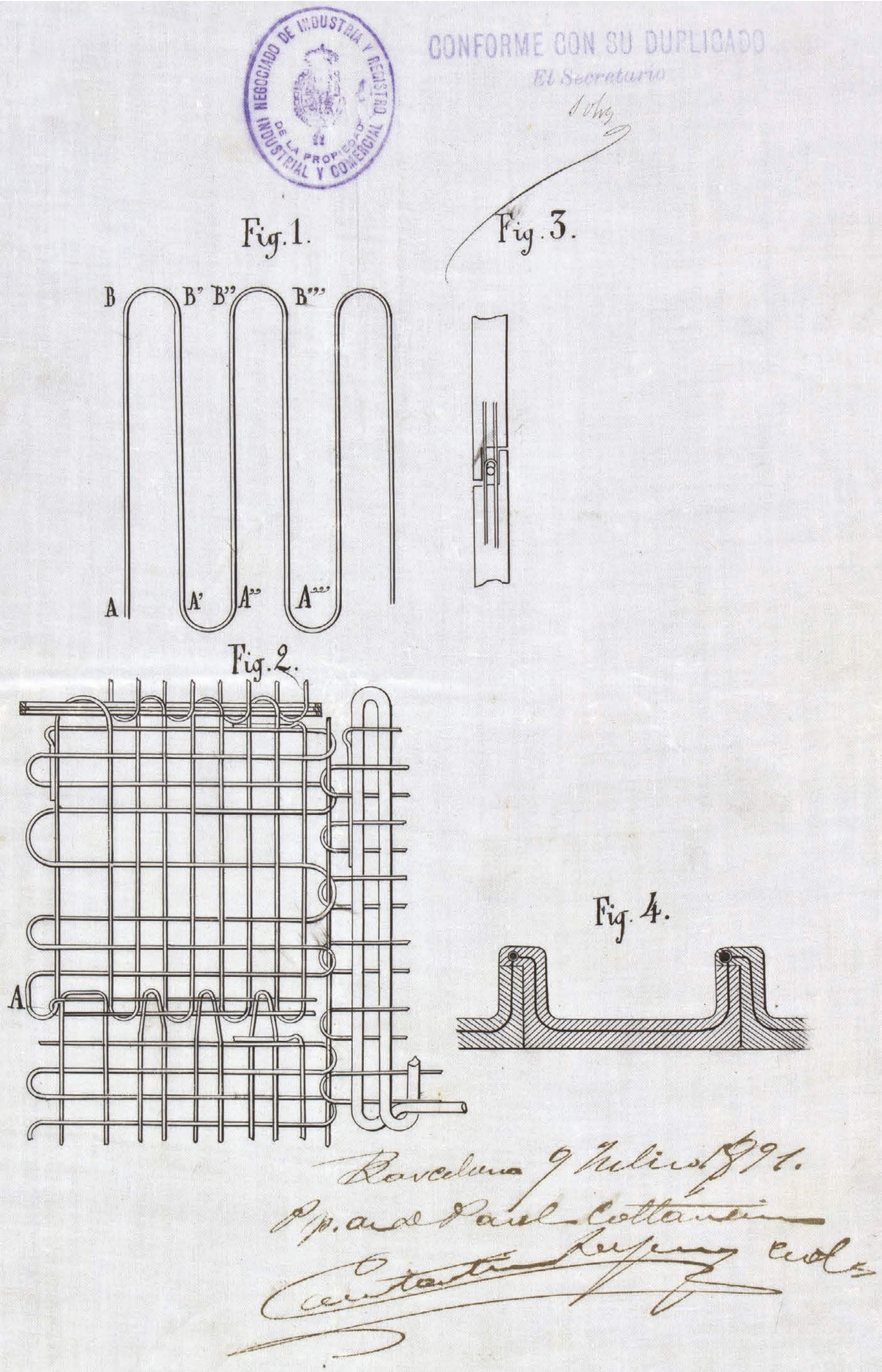

Figure 1.5.16 Cottancin, Spanish patent no. 12.301, detail, 1891.

Source: Spanish Patent and Trademark Offices, Historical Archives, Madrid.

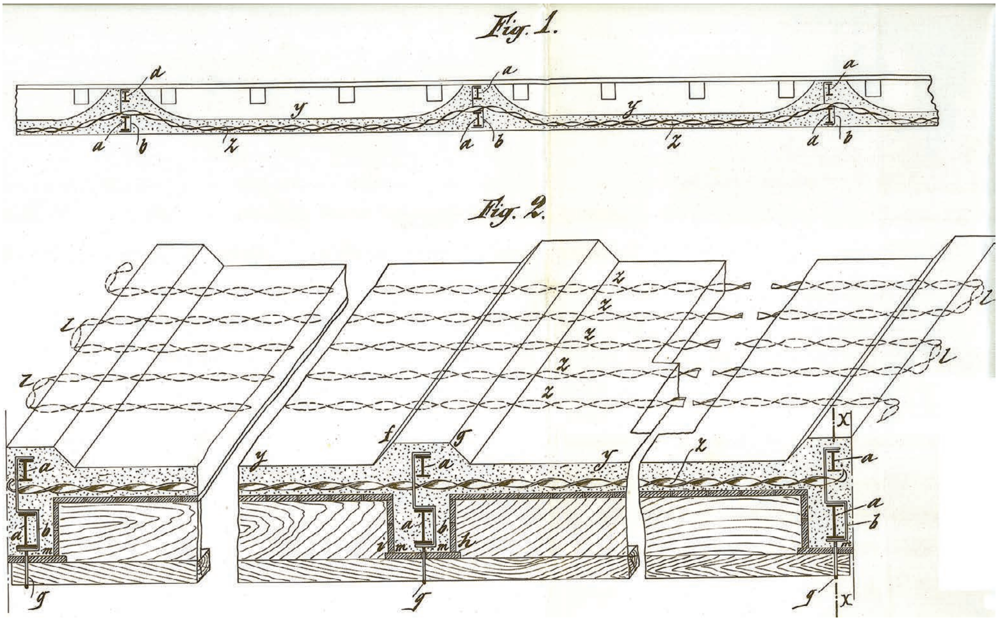

Figure 1.5.17 Habrich, Spanish patent no. 28.592, 1901.

Source: Spanish Patent and Trademark Offices, Historical Archives, Madrid.

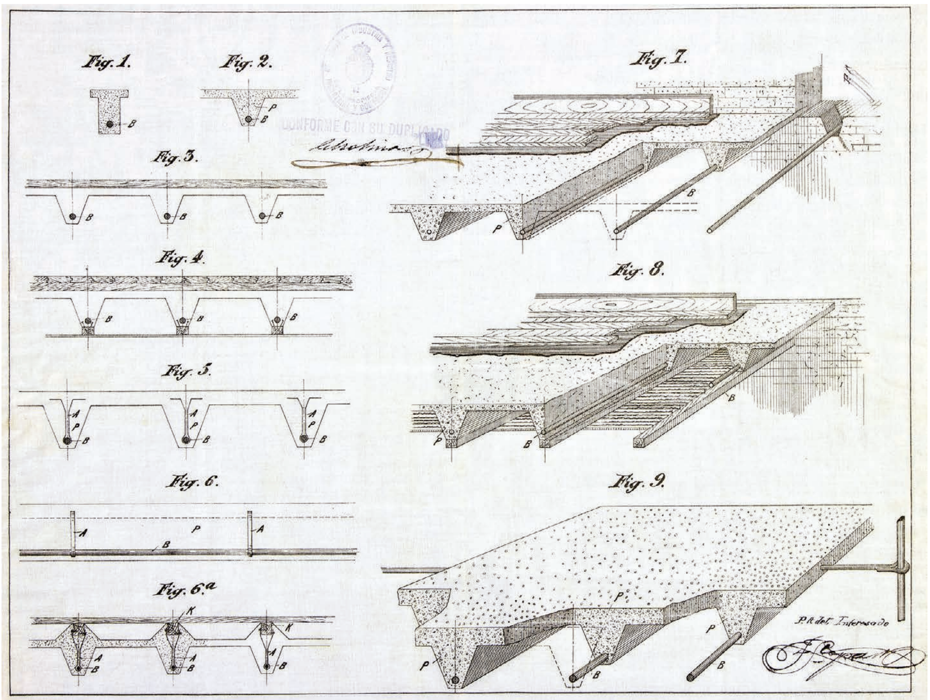

Figure 1.5.18 Hennebique, Spanish patent no. 13.652, 1892.

Source: Spanish Patent and Trademark Offices, Historical Archives, Madrid.

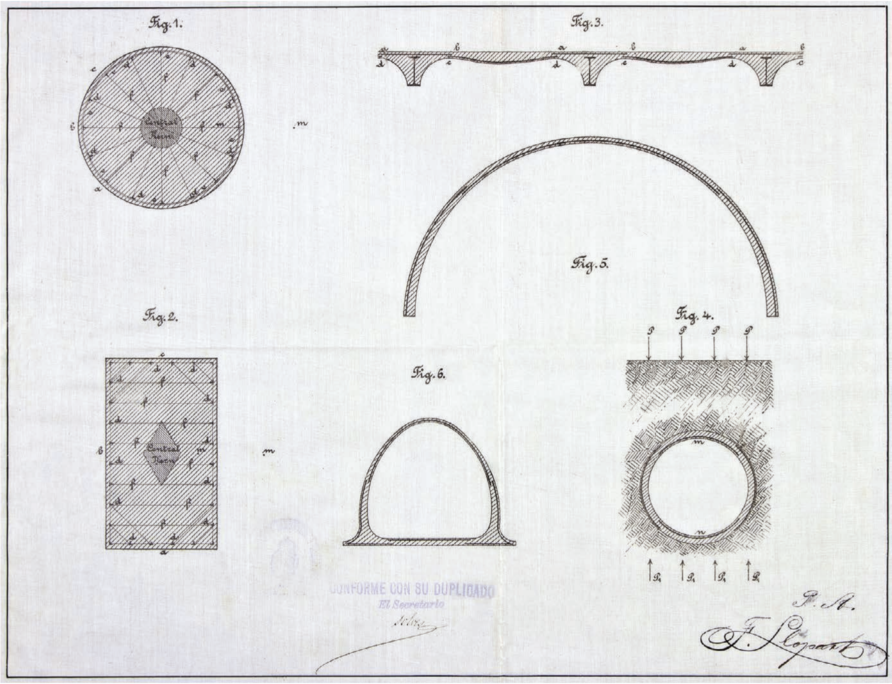

Figure 1.5.19 Koenen and Wayss, Spanish patent no. 12.920, 1892.
Source: Spanish Patent and Trademark Offices, Historical Archives, Madrid.

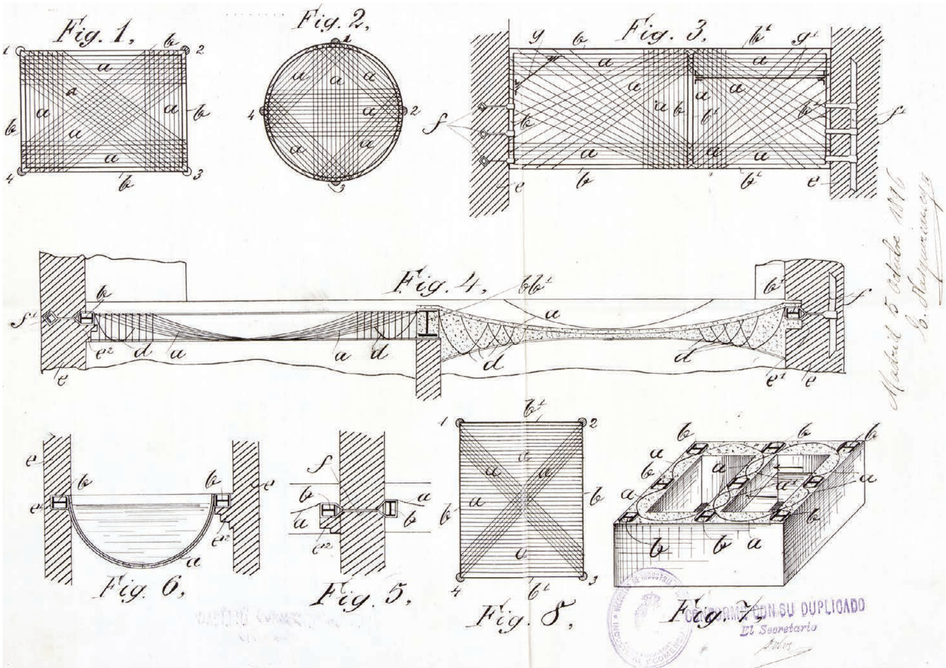

Figure 1.5.20 Mátrai, Spanish patent no. 19.732, 1896.
Source: Spanish Patent and Trademark Offices, Historical Archives, Madrid.

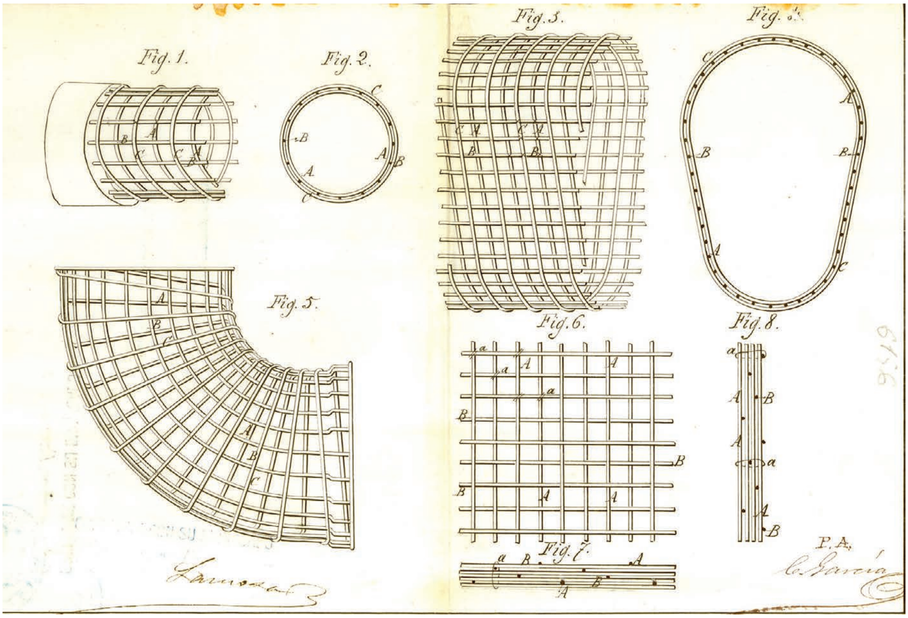

Figure 1.5.21 Monier, Spanish patent no. 6.156, 1886.

Source: Spanish Patent and Trademark Offices, Historical Archives, Madrid.

Patents Linked to Construction Companies: The Origins of Modern Building Companies in Spain

The exploitation of reinforced concrete patents gave rise to the modern construction company in Spain (Fernández Ordoñez 1982b: 20–28). New companies began developing construction in reinforced concrete based on patents, bidding for and undertaking the design and execution of projects together. The patented company not only worked as a brand but also provided technical legitimacy to the new building processes. The technical body of knowledge on calculations, the arrangement of reinforcing elements, the execution and initiation of works arrived somewhat later than the actual need to carry out works in which reinforced concrete was the ideal – and, therefore required – material. Builders and engineer professionals needed the "letter of marque",[12] which the preferred systems (those that had patents), backed up in the majority of cases by successful experiences, could provide. The exploitation of patents allowed the creation of a solid and lasting industrial building sector linked to reinforced concrete. The most important companies were active for extended periods of time and were able to implement complex systems for using reinforced concrete and experiment with innovative reinforcing structure layouts.

The first modern Spanish construction company was founded by the engineer Eugenio Ribera in this context. And during the period 1899–1906, many construction companies were established in Spain, including the following, all of which had links to foreign and national reinforced concrete patents:

- Patent: Joseph Monier. Company: Lecanda Macià y Cª, Sociedad en Comandita;
- Patent: José Eugenio Ribera Dutaste. Company: J. Eugenio Ribera y Compañía;
- Patent: Hennebique. Company: Concesionarios Hennebique;
- Patent: Ricardo Martínez Unciti. Company: Talleres Unciti;
- Patent: Blanc-Cavard, Joseph. Company: Societé Genérale des Ciments Portland de Sestao (Figure 1.5.22);

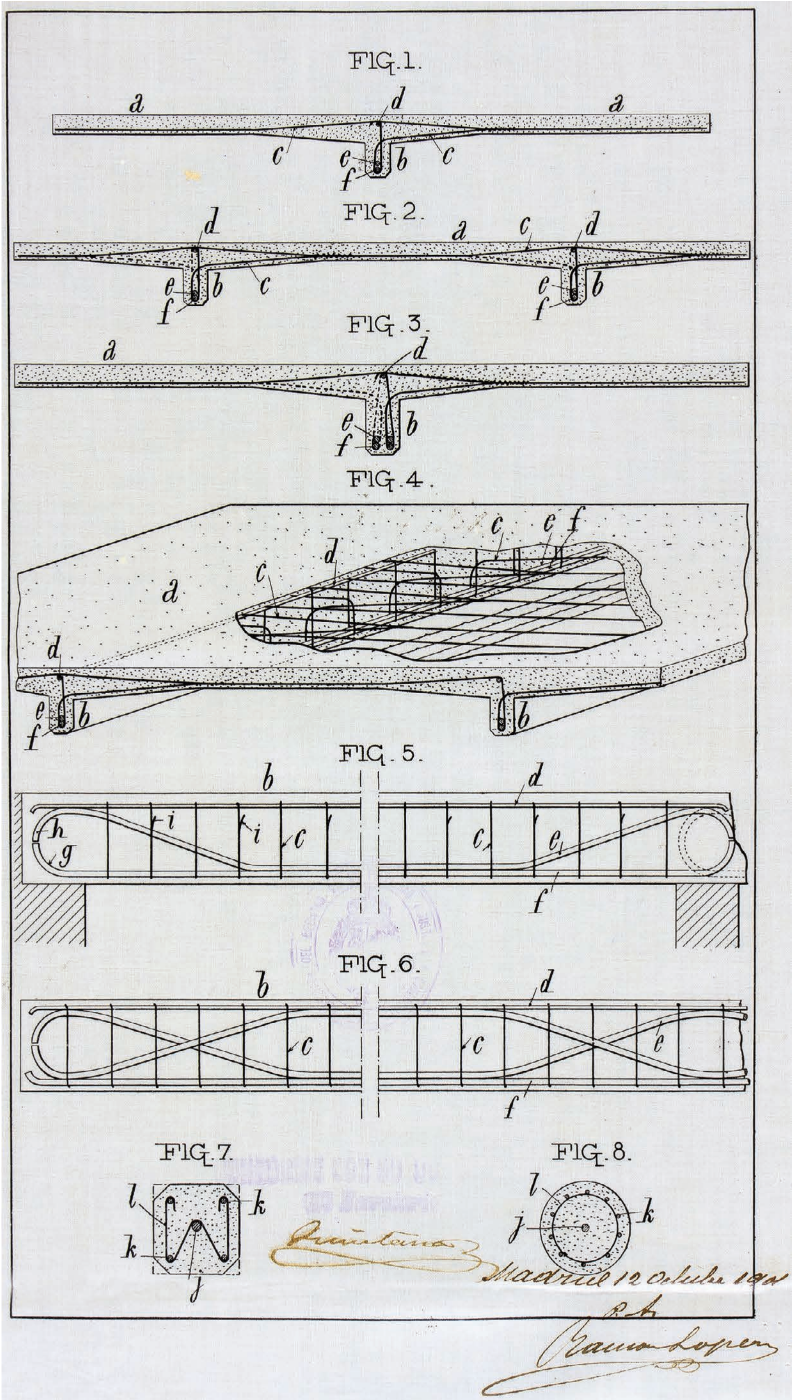

Figure 1.5.22 Blanc-Cavard, Spanish patent no. 28.633, 1901.

Source: Spanish Patent and Trademark Offices, Historical Archives, Madrid.

- Patent: Golding, John French. Company: The Expanded Metal Company;
- Patent/Company: Societé J. et A. Pavin de Lafarge;
- Patent/Company: Sociedad L. Lang & Fils;
- Patent: Mauricio Jalvo. Company: La Constructora Económica en Hormigón Armado;
- Engineer: Eduardo Gallego Ramos. Patent: Empresa Sociedad Anónima de las Aplicaciones de la Ingeniería;
- Patent: Gabriel Rebollo Canales. Company: Rebollo, Estibaus y Compañía, Sociedad en Comandita (Figure 1.5.23).

Applications of Reinforced Concrete in Construction During the Period 1884–1906

From all the registered patents registered in Spain during this period, only a selection contributed to the first-rate theoretical and technical knowledge required for the swift development of reinforced concrete in Spain during the following period, 1901–1906.

Patents That Contributed Knowledge on the Structural Forms Right for the Use of Reinforced Concrete

Just 14% of the patents improved knowledge on the best forms of reinforced concrete in terms of their structural function and, in particular, their response to bending stress. In these patents,

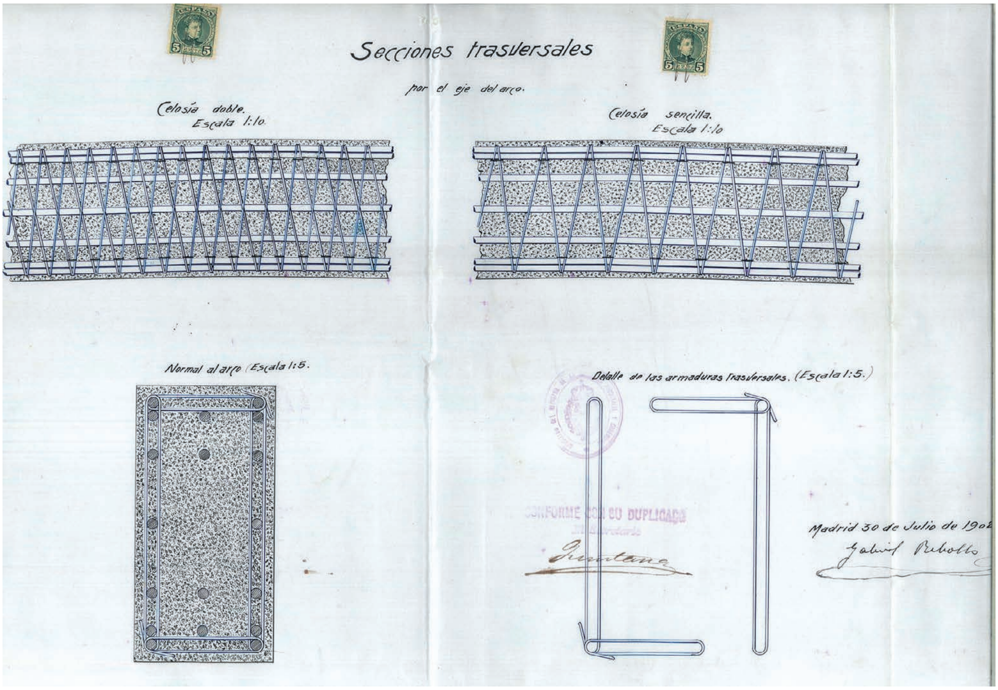

Figure 1.5.23 Rebollo, Spanish patent no. 30.145, 1902.

Source: Spanish Patent and Trademark Offices, Historical Archives, Madrid.

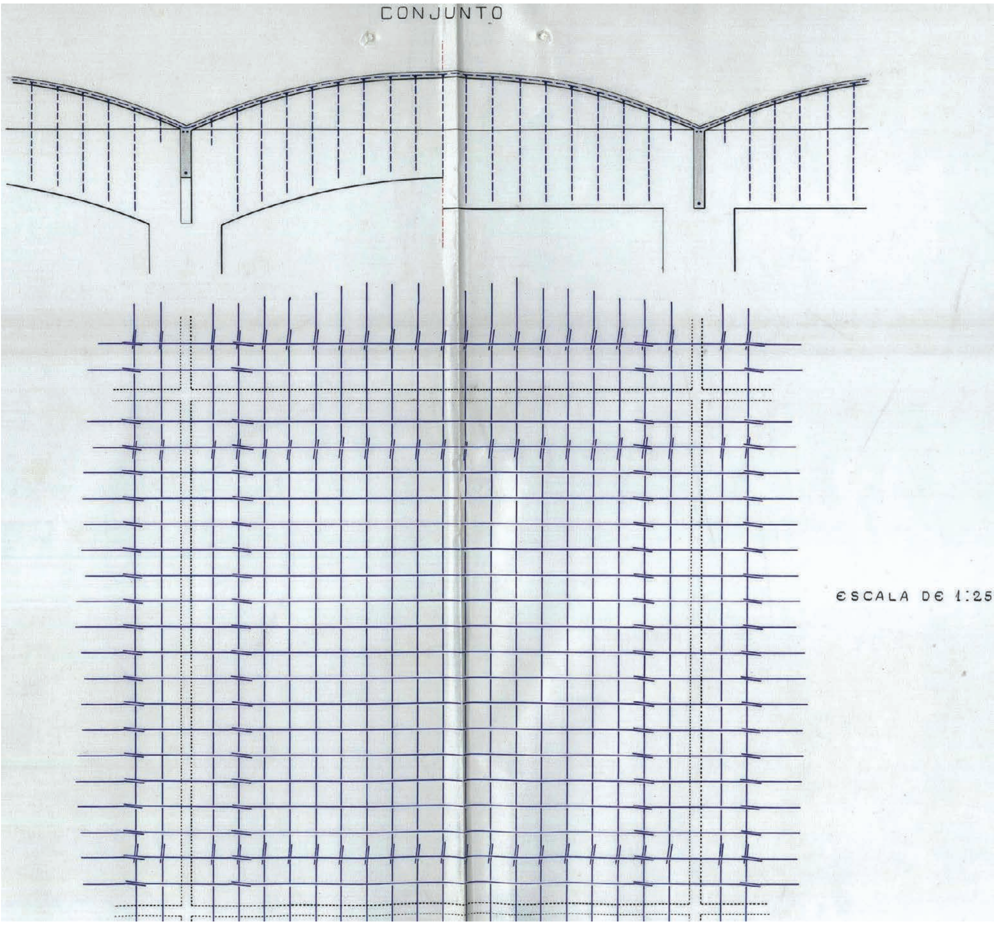

Figure 1.5.24 Zafra, Spanish patent no. 29.863, detail, 1902.

Source: Spanish Patent and Trademark Offices, Historical Archives, Madrid.

a relationship could be established between the construction properties of concrete and the form resulting from the purpose of the patent. In this regard, some 56% of these patents were registered by either Monier, Hennebique or Zafra. The last of these figures' contribution to Spanish knowledge on the best forms of reinforced concrete is clearly very important (Figure 1.5.24).

Patents That Contributed to Knowledge of the Structural Behaviour of Reinforced Concrete

The majority of patents on structural aspects were registered towards the end of the period in question. Structural patents helped professionals to develop their intuition and understand the connections between the strain to which a structure is subjected and the layout of its reinforcing elements.

The definitions of structural behaviour set out in the patents selected are essentially descriptive in nature. Some patents included diagrams that described the expected behaviour of the material under tension (moments and shear forces). Only two of the patents offer brief mathematical formulas.

Despite the fact that at the start of the period in question, structural approaches were far more advanced in other countries than in Spain, figures such as Zafra, Ribera and Rebollo were caught up in the space of a few years when it came to an understanding of the structural behaviour of reinforced concrete. Juan Manuel de Zafra was behind 4 of the 13 patents that contributed to knowledge of the structural behaviour of reinforced concrete (Figure 1.5.25).

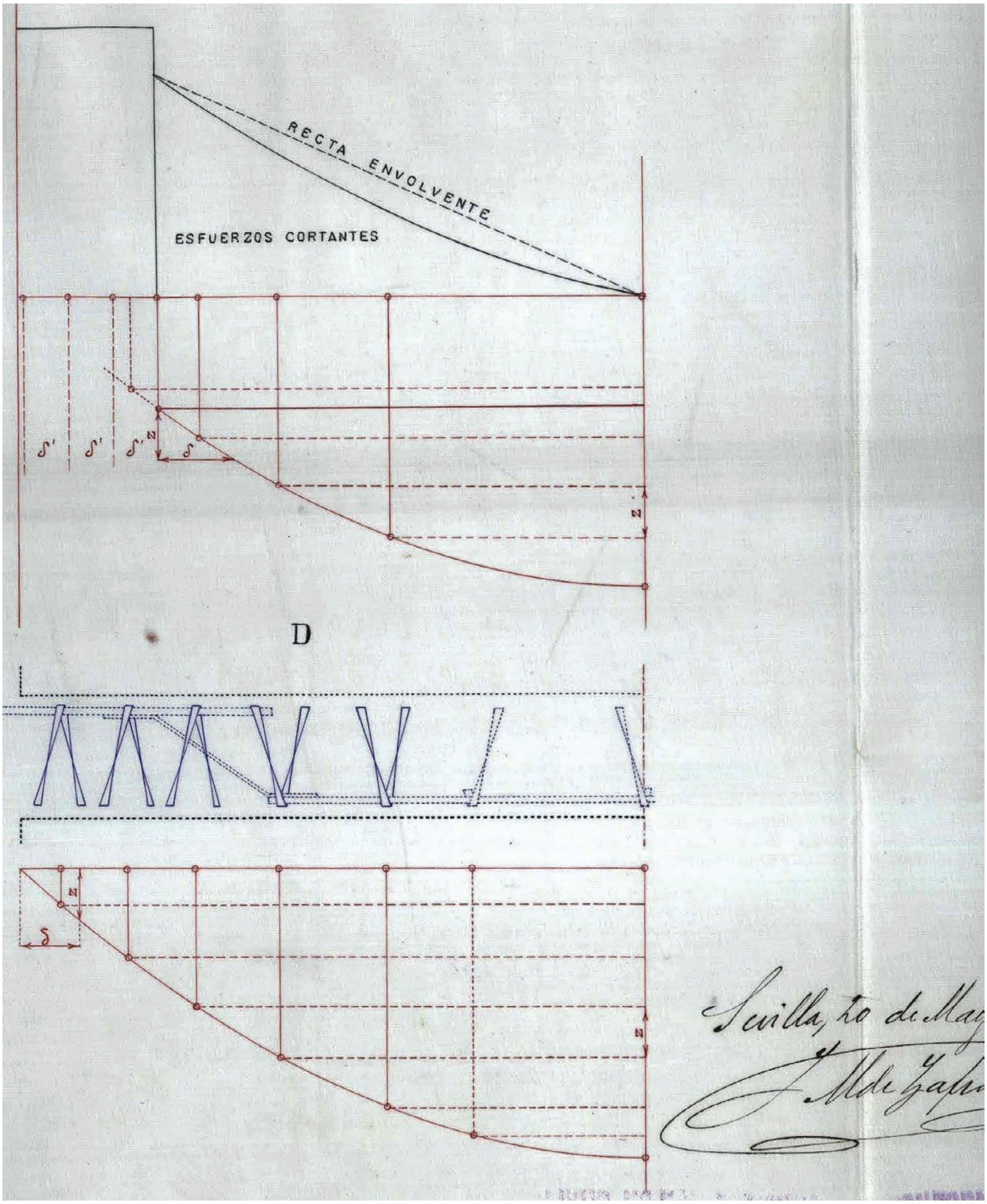

Figure 1.5.25 Zafra, Spanish patent no. 29.864, detail, 1902.

Source: Spanish Patent and Trademark Offices, Historical Archives, Madrid.

Patents That Contributed to Knowledge on the Layout of Reinforcing Elements in Reinforced Concrete

During the period in question, the most important international patents were those providing knowledge on the correct layout of reinforcing elements in reinforced concrete. This group included two Spanish engineers: Zafra and Rebollo. Monier (Figure 1.5.26), Hennebique and Zafra were responsible for 56% of the significant patents in the field registered in Spain.

The layout of reinforcing elements contained in Hennebique's patents was the most accurate, responding to bending and shear stresses with longitudinal bars and well-placed stirrups and ties (Figure 1.5.27). Hennebique introduced the three-dimensional representation of reinforcing elements (Figure 1.5.28), displaying the complexity of the way the bars were crossed within the structures.

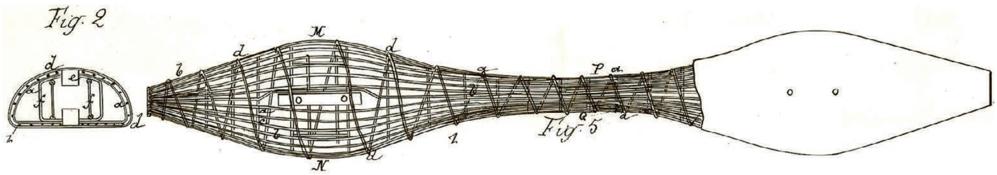

Figure 1.5.26 Monier, Spanish patent no. 4.433, detail, 1884.

Source: Spanish Patent and Trademark Offices, Historical Archives, Madrid.

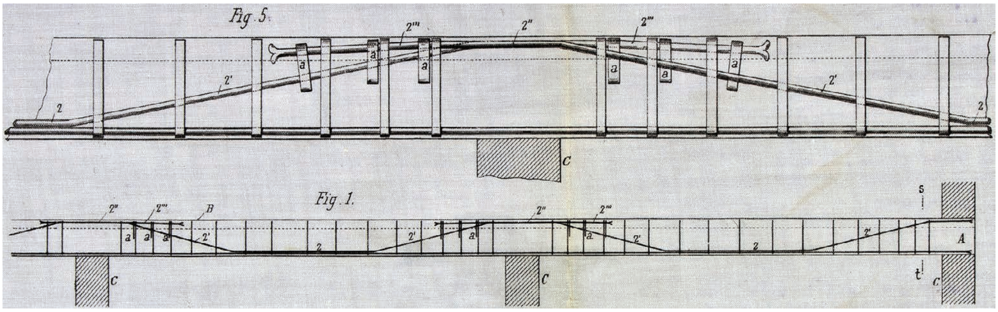

Figure 1.5.27 Hennebique, Spanish patent no. 22.304, detail, 1898.

Source: Spanish Patent and Trademark Offices, Historical Archives, Madrid.

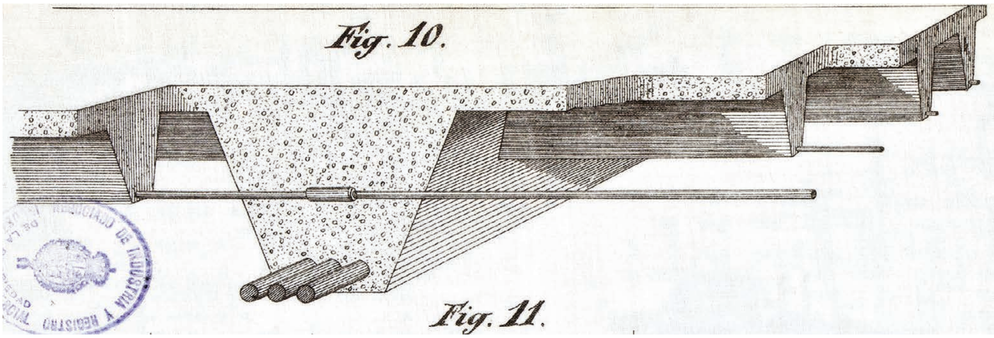

Figure 1.5.28 Hennebique, Spanish patent no. 13.652, detail, 1892.

Source: Spanish Patent and Trademark Offices, Historical Archives, Madrid.

Zafra's patents were the first to introduce the concept of the overlap length, or lap length, required to ensure the continuity of the reinforcing elements, which was defined in line with the diameter of the bars. In this regard, to a certain extent, Zafra used his four patents as four short introductory manuals on reinforced concrete techniques (Figure 1.5.29).

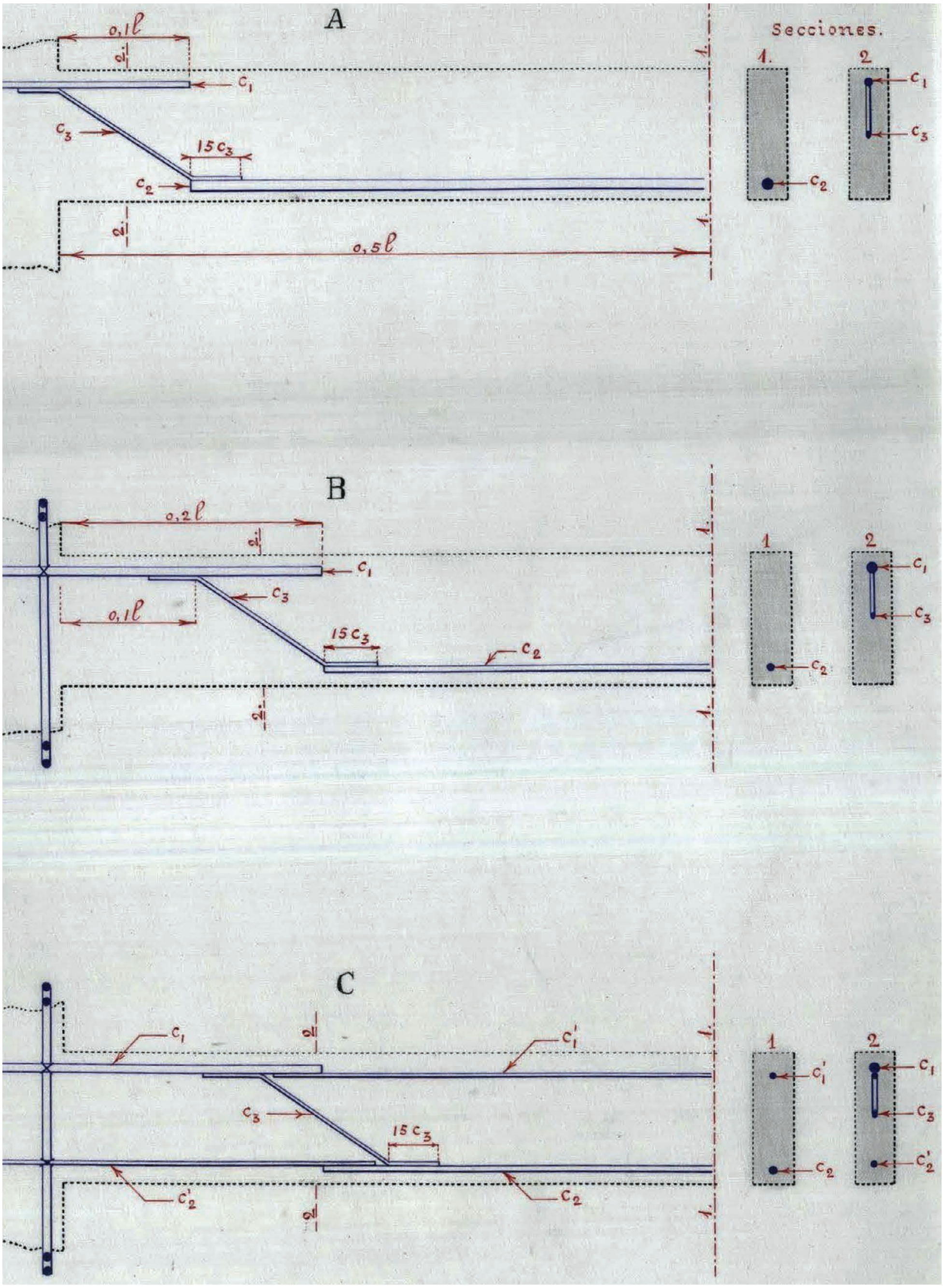

Figure 1.5.29 Zafra, Spanish patent no. 29.864, detail, 1902.

Source: Spanish Patent and Trademark Offices, Historical Archives, Madrid.

Patents That Contributed Industrial Technology Designed to Improve Reinforcements and the Manufacture of New Products

From the outset, in 1886, Spain had at its disposal a reinforcing element that contributed technology and industrialization to the construction industry: expanded metal. Despite many improvements to reinforced concrete components being imported from France or England, expanded metal patentee John French Golding was from the USA, and its first exploitation took place in England. Patents focusing on industrialized reinforcements were scarce and reduced mainly to Golding (métal *déployé*) and Coignet (Figures 1.5.30 and 1.5.31).

Other patents incentivized the import of improved industrial technology (machinery) destined for the manufacture of objects, including concrete tubes. This imported technology was swiftly transferred also to the construction sector and constituted a fundamental factor in the evolution of construction in reinforced concrete. In the space of just a few years, this technology provided Spanish industry with capabilities similar to those found in the other advanced countries.

Patents That Supported the Development of the Prefabrication and Industrialization of Reinforced Concrete

Prefabrication of reinforced concrete derivates took place throughout the period analysed, from 1886 to 1906. The patents for prefabricated systems and elements, which were mainly foreign in origin, provided the Spanish construction sector with a knowledge of complex manufacturing processes and conditioned technicians to tackle problems such as the continuity of

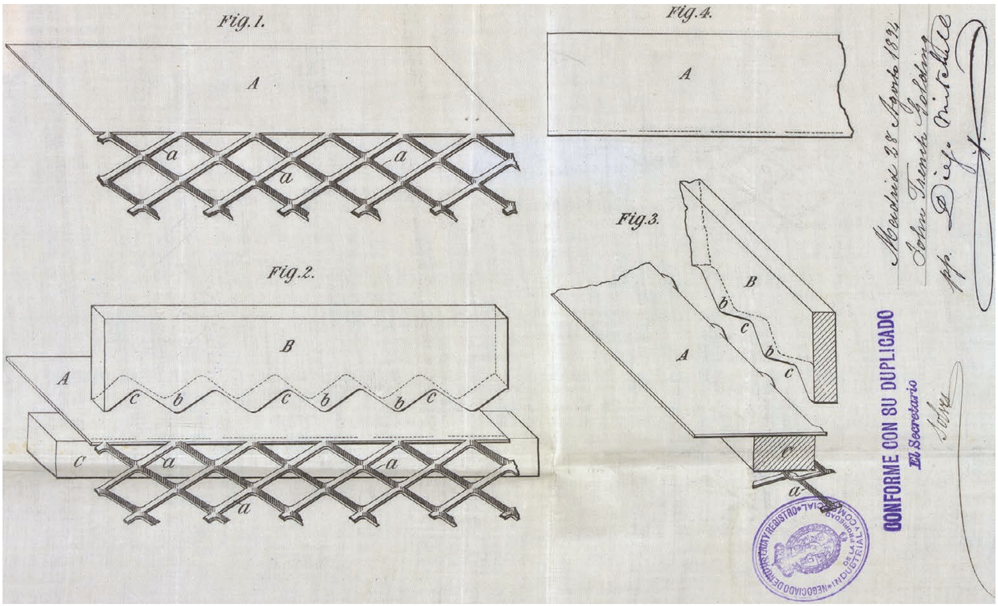

Figure 1.5.30 Golding, Spanish patent no. 16.224, 1894.

Source: Spanish Patent and Trademark Offices, Historical Archives, Madrid.

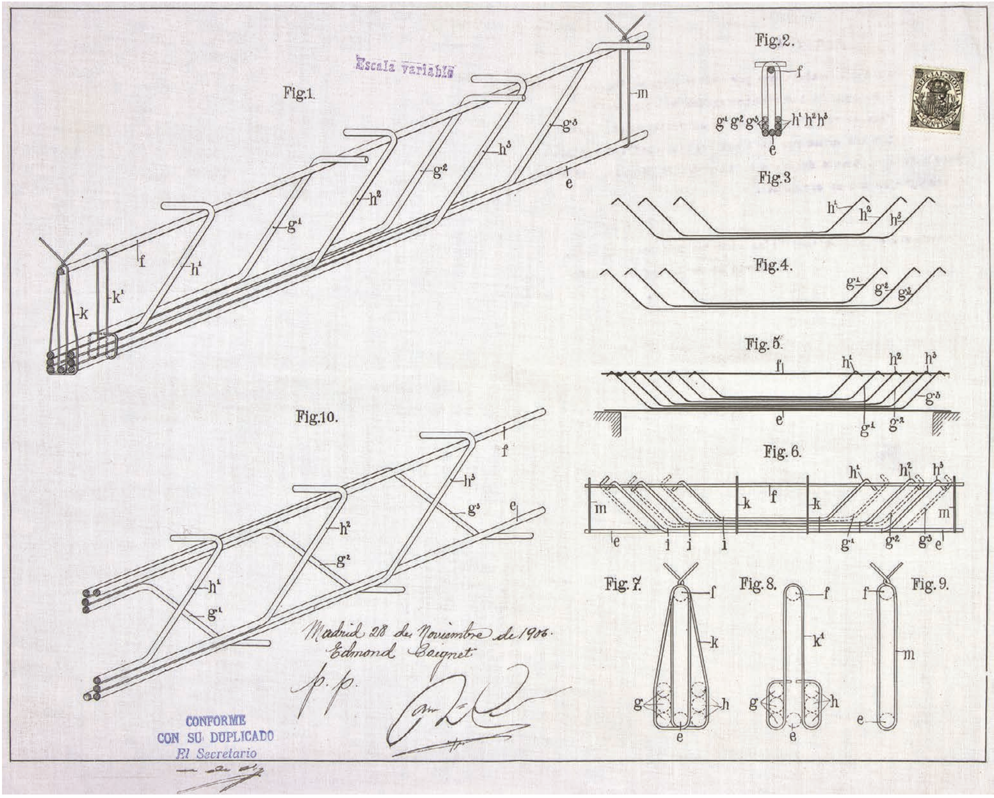

Figure 1.5.31 Coignet, Spanish patent no. 39.535, 1906.

Source: Spanish Patent and Trademark Offices, Historical Archives, Madrid.

prefabricated elements, their structural behaviour, the layout of reinforcing elements and so on. Prefabrication required technology other than the execution of in-situ reinforced concrete. This technology encouraged and boosted improvements to reinforced concrete construction in Spain (Figures 1.5.32, 1.5.33, 1.5.34, 1.5.35 and 1.5.36).

The patents for prefabricated systems and elements contributed new structure types and previously unknown techniques that had not been widely disseminated until then, such as prestressing. Prefabrication was not regulated in the French ministerial regulations on the use of reinforced concrete, published on 20 October 1906, and patents continued to have a scientific/speculatory nature that offered value for the construction sector. This contribution was fundamental to the development of construction in reinforced concrete in Spain and the future development of its applications.

In this sense, we can highlight the figure of engineer Bernardo de la Granda y Callejas (1871–1968), who in 1904 patented the first Spanish system of prestressed concrete, which was possibly one of the first of its kind worldwide (Figure 1.5.37). Two years later, the second prestressed concrete patent was registered in Spain by the Belgian engineer Edmond Joseph Sacrez (Figure 1.5.38).

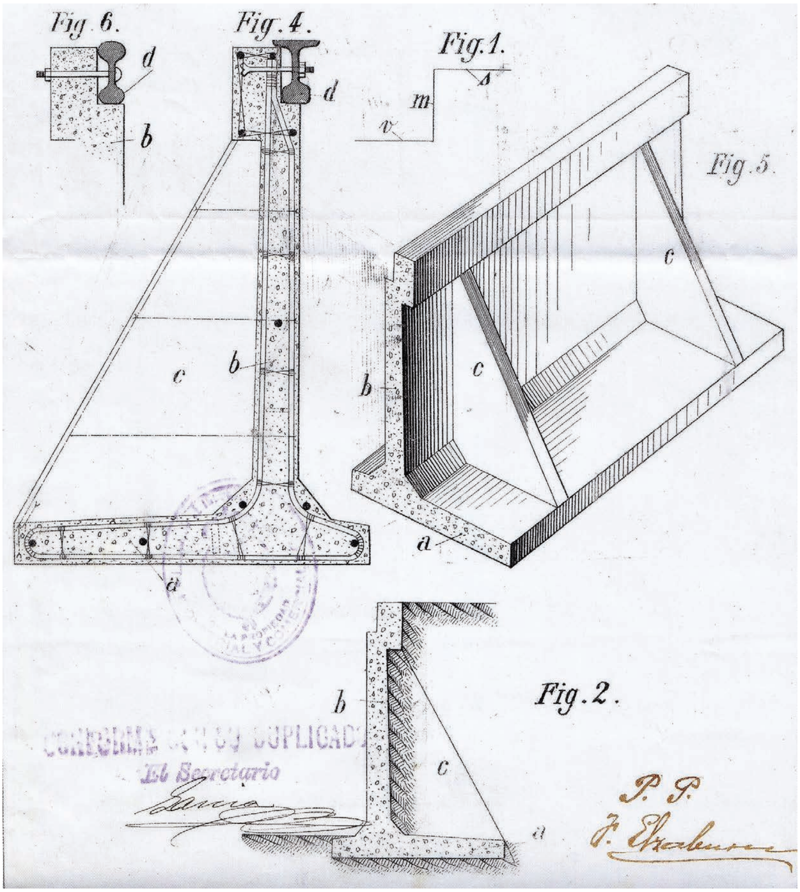

Figure 1.5.32 Hennebique, Spanish patent no. 25.990, detail, 1900.

Source: Spanish Patent and Trademark Offices, Historical Archives, Madrid.

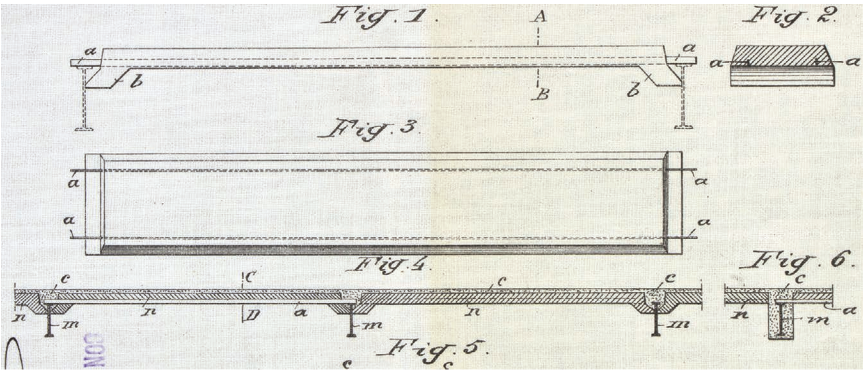

Figure 1.5.33 Parcy, Spanish patent no. 28.475, detail, 1901.

Source: Spanish Patent and Trademark Offices, Historical Archives, Madrid.

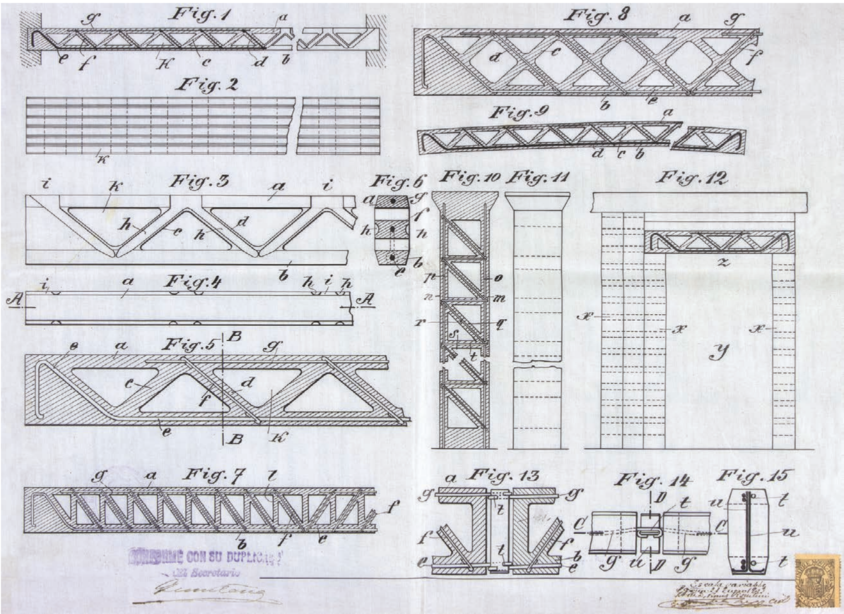

Figure 1.5.34 Visintini, Spanish patent no. 31.097, 1903.

Source: Spanish Patent and Trademark Offices, Historical Archives, Madrid.

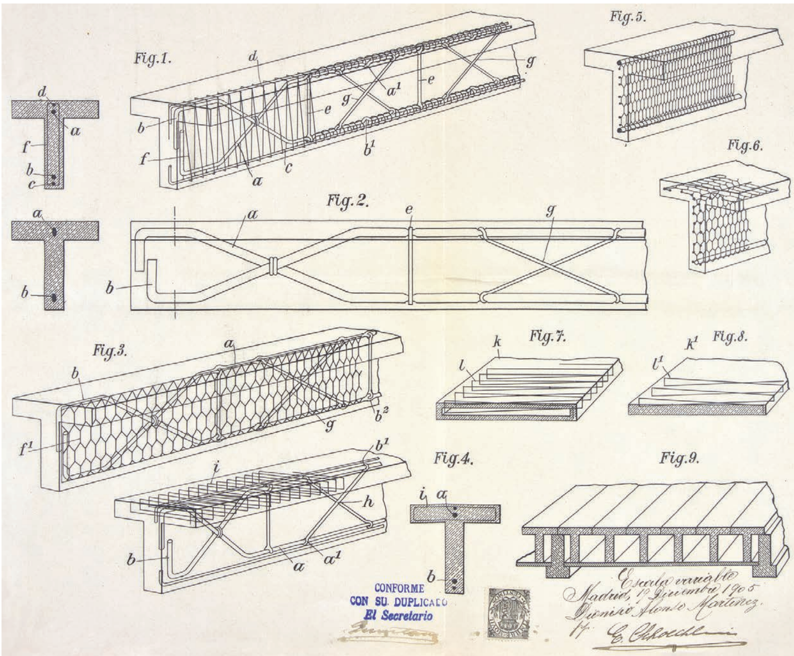

Figure 1.5.35 Lavanchy, Spanish patent no. 37.371, detail, 1906.

Source: Spanish Patent and Trademark Offices, Historical Archives, Madrid.

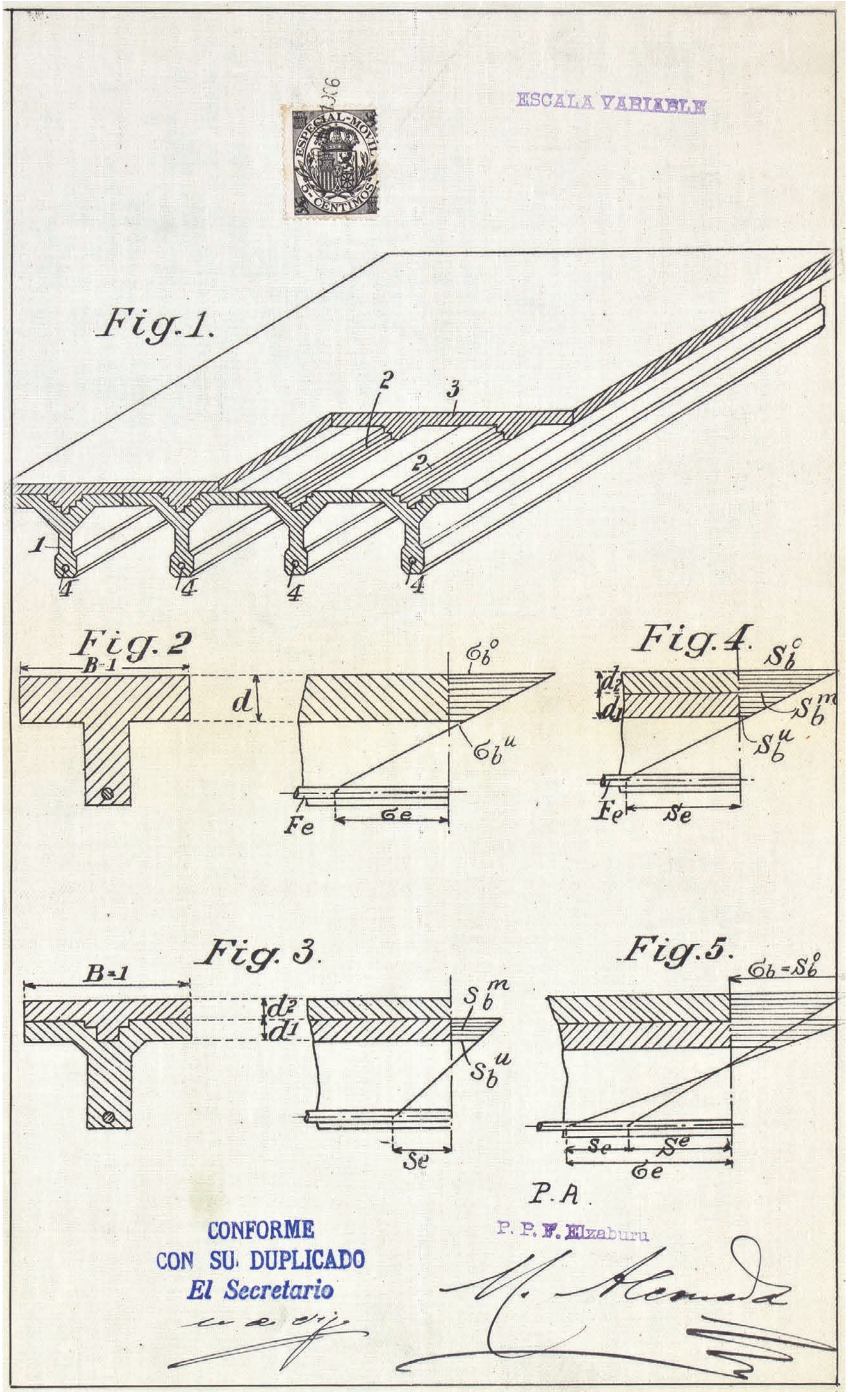

Figure 1.5.36 Bayer, Spanish patent no. 38.624, 1906.

Source: Spanish Patent and Trademark Offices, Historical Archives, Madrid.

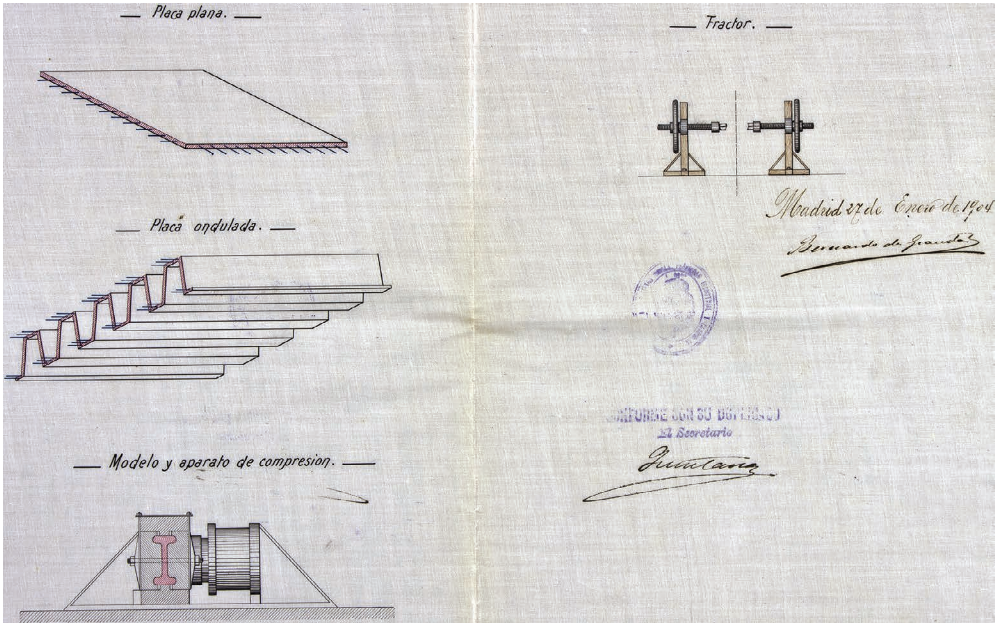

Figure 1.5.37 Granda Callejas, Spanish patent no. 33.301, 1904.

Source: Spanish Patent and Trademark Offices, Historical Archives, Madrid.

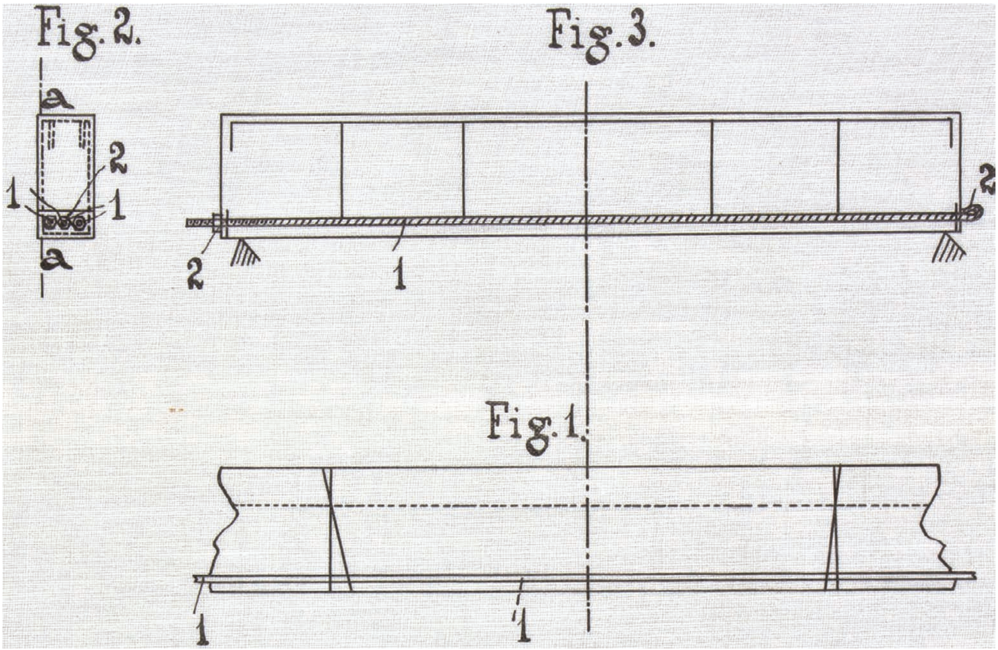

Figure 1.5.38 Sacrez, Spanish patent no. 39.541, 1906.

Source: Spanish Patent and Trademark Offices, Historical Archives, Madrid.

Conclusion

The patents registered in Spain during the period 1884–1906 fulfilled the aim of transferring existing foreign knowledge on reinforced concrete into the Spanish construction industry to serve the various purposes detailed in this study. This transfer of knowledge was one of the reasons for the evolution of this construction technique in the country.

Despite incorporating reinforced concrete in its culture of building more than two decades later than other European countries, Spain made up for lost time in just over six years (1901–1906). Patents played a vital role in this process.

Notes

1 Collins reminds us that Joseph Lambot's boat and de Monier's jardinieres are no more than specific applications of a procedure already employed by Henri Labrouste when he created his vaulted roof of reinforced plaster for the Sainte-Geneviève Library in Paris.
2 The first course on reinforced concrete constructions was imparted by Charles Rabut (1852–1925) at the École Nationale de Ponts et Chaussées in Paris in 1897. Surviving notes taken by the students who attended these early courses tell us that Rabut started his classes by referring to materials with little or no resistance to traction, to which other materials were added to improve their behaviour, for example, clay walls incorporating straw or masonry lintels reinforced with metal elements.
3 Although some authors attribute the invention of reinforced concrete to the British builder William Boutland Wilkinson (1819–1902), who specialized in plaster and concrete decoration, which he termed "artificial stone". In 1854, he filed for a patent for a reinforcing system using steel framework. The aim was to improve the fire resistance of buildings. The system consisted in the use of plaster panels that served as lost formwork into which concrete was poured. The concrete was reinforced with iron bars, resulting in a kind of grid structure.
4 Exploitation rights for a patent cost between 15% and 20% of the total construction costs.
5 According to Ransome, the period of inventions in reinforced concrete ended in 1904 with the patent granted to Considère for a system of pillars with helical reinforcement.
6 Some 82.7% of these patents came from abroad.
7 In 1895, this company had built more than 40 structures using the Monier system of reinforced concrete.
8 The concrete slabs used were subject to a prior trial that had become famous among Spanish technicians thanks to its dissemination in the *Revista de Obras Públicas*. Calculated to support a load of up to 250 kg/m^2, the slabs in fact did not break until subjected to a load 11 times greater, some 2,800 kg/m^2. Reinforced concrete slabs' exceptional elasticity and deflection recovery were also demonstrated. The deflection disappeared on the removal of a load of 1,200 kg/m^2, some 2.5 times original calculations.
9 Hennebique sent works managers specializing in the execution of structures in reinforced concrete from Paris.
10 This is the hypothesis I have defended and substantiate in my doctoral thesis.
11 The percentage of patents licensed is a very useful and valuable indicator, since it indicates the number of inventions that were directly applied in production or construction, and which can by definition be considered innovations. The licensing of patents for inventions in reinforced concrete is the reason – in construction terms – for the technological evolution of this material. Although the licensing of a patent for a reinforced concrete invention is the best marker of the evolution of the material in the construction industry, the fact that an invention was not put in practical use does not mean that the knowledge was not transferred into the sector. A quality patent might not be put in practice because it was ahead of the needs of its time, lacking the support of the industry required for it to be exploited.
12 Juan Manuel de Zafra's exact words cited here.

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Chapter 1.6

Belgium's International Reputation in the History of Concrete

Blaton, Christophe, Franki, Hennebique, Magnel and Others

Bernard Espion

Introduction

Why does Belgium enjoy such international renown in the history of concrete? The answer is that since the late 19th century, Belgium has been the home of outstanding businesses and technological innovations which have shaped the development of the international concrete industry. In addition to the commercial and industrial achievements of various large groups which have expanded their activities around the world, Belgium is also home to a thriving academic and scientific research community that has been involved in many international conferences, publishing houses, books and specialist journals. Since the archives of Paul Christophe and the Franki, Hennebique and Blaton companies were opened, new light has been shed on an important chapter in construction history as a result of inter-university research by multidisciplinary teams, for whom the author serves as a spokesman in this chapter.

Concrete Before Reinforced Concrete

Concrete was not invented in the 20th century – or even the 19th century. Its origins are much older, dating back to antiquity. Vitruvius, writing in the 1st century BC, gives "recipes" for the composition of concrete in his treatise *De Architectura*. And Roman builders made abundant use of this material, most probably preceded by the Greeks.

Until the invention of artificial cement in the first half of the 19th century, the hydraulic binder used in the composition of concretes and mortars was lime, a material resulting from the calcination of limestone. Rather than recounting the history of the discovery of the hydraulicity of lime, and the subsequent invention of artificial cement, it will suffice here to quote the French military engineer Bernard-Forest de Belidor (1698–1761) in his book *La Science des Ingénieurs* (Belidor 1729). Considered to be the first encyclopaedia of engineering and construction, this book was widely available to engineers in Europe in the 18th century and valued so highly that it was again reissued by Claude-Louis Navier (1785–1836) in 1813.

> Apart from the Terras [*sic*] of Holland,[1] there is a powder still in use in Flanders commonly called Tournay Ash, which is usefully employed in the composition of the mortar for structures in water. Since no-one (to my knowledge) has adequately explained its properties and its manner of use, I will report what I know in a few words. In the area around Tournay there is a very hard type of blue stone which makes excellent lime. When this stone is in the kiln, small pieces detach and fall under the grate of the furnace, where they are mixed with the ashes of the coal; and as this ash is nothing other than small pieces of calcined coal, the resulting mixture makes Tournay Ash, which is sold by the merchants exactly as it is removed from the

DOI: 10.1201/9781003368656-8

> furnaces. As experience has shown that [Tournay] hard stone always makes good lime and an excellent mortar for water structures when it is mixed with powder from coal or slag taken from forges [. . .] it is no wonder that Tournay Ash is wonderful for the same purpose, since it combines the qualities of both materials. For I have no doubt that the small parts of coal which are mixed with the ash will contribute greatly to giving it the property of hardening in water, as discussed below. [. . .] This ash is used for the masonry of locks, bridges, aqueducts, coffer-dams, etc., and generally in ordinary masonry to entrench and repoint sandstone; this needs to be done between April and the end of July because, employed during that time, it never bursts, which is a remarkable property of the ash, as most cements are subject to chapping: Boulogne lime, for example, which is excellent when it is used in water, is worthless when dry.
>
> (Belidor 1729: 16–17, translation by the author)

A summary of that text also appears in Volume 9 (in the article on Masonry) of the *Encyclopédie* by Diderot and d'Alembert published in 1765. What does this tell us? That Tournay limestone was known for producing excellent limes, whose hydraulic power – that is to say, the property of hardening under water – could be increased by the addition to the "terras lime from Holland" (actually "trass" from Andernach in Rhineland) or "Tournay Ash". In both cases, we are dealing with pozzolanic materials. Portland artificial cement, which requires the calcination of limestone at a much higher temperature (1450°C) than that required for obtaining lime (about 900°C), did not become commercially available until the middle of the 19th century in Great Britain, France and Germany, but within 20 years, in 1872, it was being produced in Belgium on the site of Cronfestu, Morlanwelz (Dutron 1948: 163). However, excellent concretes can be made with lime or with natural cements. Thus, for a long time, the Tournay region remained a producer of natural cements, and it was not until the early 20th century that Portland artificial cement factories began to be located there (Dutron 1948: 163).

As a pozzolanic material supplement to lime – or even cement – trass was widely used during the 19th century not only in Germany (Aprea 2016) but also in Belgium (Moreau 2020: 12). A remarkable example of a large concrete construction in Belgium made from concrete with a binder consisting of lime hydraulically enhanced with trass is the Gileppe gravity dam (Figure 1.6.1) built near Verviers (1867–1878) following the designs of engineer Eugène Bidaut (1808–1868). The original height of the dam was 45 m,[2] and the length of its crest was 235 m (Bodson et al. 1876). At that time, it was one of the largest and tallest masonry gravity dams in the world.

In 1865, Adolphe Blaton (1835–1905) and his wife Adèle Aubert (1838–1903) established a building materials trading business in Brussels (Pesztat et al. 2017). This company, Blaton-Aubert, was the first in a series of family businesses closely linked to the history of the use and construction of concrete structures in Belgium, and even internationally. Some advertisements published in the press give an indication of the activity of the company, which occupied premises at Rue du Trône at the time:

> Tanks – Flooded cellars: I undertake work at a fixed price and offer a 20-year guarantee on all kinds of hydraulic structures such as tanks for water, spirits, petroleum oils and other oils – Gasometer tanks – Tannery pools – Coolers – Sealing of damp cellars – Sanitation of damp and saltpetrous walls – Coal works – Construction of rocks, Caves, Aquariums, etc. Economy. We indicate how to use cement for customers who wish to carry out the work at their own risk. Warehouses of Portland and other Cements. Andernach Trass – Plasters – Barium sulphate – Laying of cement tiles.
>
> (translation by the author)

Figure 1.6.1 The Gileppe concrete dam under construction (n.d., before 1878), Jalhay, Belgium.
Source: Royal Library of Belgium (S.I 49333).

In 1877, the list of cements marketed by Blaton-Aubert included (again, according to an advertisement in the press) no less than eight cements: English Portland cement, Keene's white cement (i.e. a gypsum cement or quick setting finishing plaster), French Portland cement, cement from Vassy (a natural cement), Roman cement, natural cements, refractory cements and cements for artificial stone. It will be noted that this advertisement does not promote Portland cement produced in Belgium, which was then deemed inferior to imported artificial cements. In 1875, the company participated in exhibitions abroad, and then in Belgium, showcasing in particular its expertise in the realization of artificial rockworks imitating nature. The oldest structure of this type to have survived is the grotto at the ponds of Ixelles (Figure 1.6.2), built in 1876 and renovated in 2016 (Louis 2017).

In 1876, the company moved to Rue du Pavillon in Schaerbeek, to a site and buildings that would allow real industrial activity to develop. From this date, production commenced of compressed cement tiles and moulded concrete objects, especially statues, vases and pedestals, which were acclaimed at exhibitions in Paris in 1878 and Brussels in 1880. The Brussels company was certainly not the first or only producer of these kinds of concrete objects in Europe (and these should more properly be described as being rendered in mortar opposed to concrete); nevertheless, the businessman and philanthropist Adolph Sutro (1830–1898) placed an order with Blaton-Aubert in 1883 for almost 200 items of this type to adorn the park – open to the public – on his property overlooking the Pacific Ocean in San Francisco (Sutro Heights), some of which are still there today. Many traces of these kinds of artificial rocks, concrete garden

Figure 1.6.2 Grotto and Greek Temple – artificial rockworks in "concrete" (1876).
Source: Ixelles pound, Brussels. Photo credit: by the author, 2017.

furniture or ornament imitating nature, of which Blaton was not the only but certainly the best-known producer in Belgium, can be found in the built heritage, even in the architecture of houses (Figure 1.6.3).

By the late 1870s, Blaton-Aubert was promoting applications of rammed concrete and agglomerated concrete, terms which strongly echo the promotion of "agglomerated concrete" in France by François Coignet (1814–1888). This same reference to Coignet's agglomerated concrete was made by the mayor of Laeken, Emile Bockstael (1838–1920) – himself an engineer – at the Municipal Council in 1880 when awarding Blaton-Aubert the first contract for concrete funerary galleries for the cemetery of Laeken, a suburb of Brussels.

The compressed concrete sewer pipe was another flagship product of Blaton-Aubert in the 1880s. The company constructed sewers in several Belgian cities using precast pipes or by pouring the concrete in place.

Finally, at the turn of the 1890s, a vast amount of (non-reinforced) mass-rammed concrete was used to construct, within a short period of time (1889–1891), the belt fortifications around Liège (12 forts) and Namur (9 forts) designed by General Henri Alexis Brialmont (1821–1903). French companies (Richou 1902) were retained to complete this colossal undertaking which entailed enormous logistical challenges (Figure 1.6.4); it required the consumption of about 300,000 tonnes of Portland cement, well above the level of national production at the time.[3] A large proportion of the cement used, therefore, had to be imported (Moreau 2020: 16).

Figure 1.6.3 Villa "Les Trois Canada" (1905), Avenue Van Becelaere, Watermael-Boitsfort, Brussels.

Photo credit: by the author, 2010.

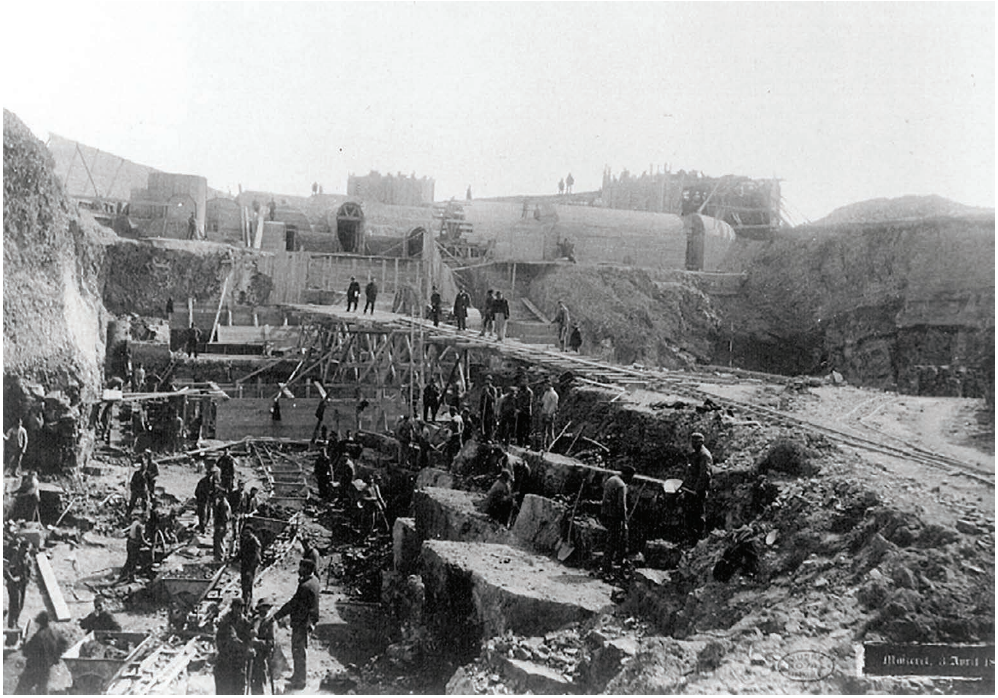

Figure 1.6.4 Construction of the Maizeret fort (1890).

Source: Royal Military Museum Brussels.

Early Reinforced Concrete Until 1914

Different origins and several inventors may have been credited with the arrival of reinforced concrete in the second half of the 19th century, but as far as Belgium, France, Italy, Spain, Portugal, part of Switzerland, Great Britain and some other countries are concerned, it is instructive to recall the speech given by François Hennebique (1842–1921) before participants at the third Congress of his organization in Paris in 1899:

> Gentlemen, reinforced concrete was born in Belgium; it was born of a French father in a foreign country. But I must say, however, that I was no foreigner in Belgium. [. . .] When I invented this system and I wanted, in 1892, to call the attention of the public authorities to my construction, I succeeded in swiftly attracting the attention of the administration, the ministries engaged in building. A committee was appointed from each ministry and they came to examine my work. Reports were more or less favourable. [. . .] Today, returning to France as a foreigner – for I have to tell you that I experienced once again that no-one is a prophet in their own country – coming back from Brussels, crossing the border, I was a Belgian.
>
> (Hennebique 1899: 2; translation by the author)

Indeed, for Belgium, reinforced concrete did not exist before Hennebique (Van de Voorde 2011; Hellebois 2013). Originally a small masonry contractor born in the Pas-de-Calais, France, Hennebique settled in Belgium early on. In 1889, he produced his first reinforced concrete floor in a villa at Lombardsijde (Middelkerke) to meet the owner's requirements for fireproofing (Van de Voorde 2011: 42). Fire resistance would subsequently become the recurring argument invoked by Hennebique to promote the material. Hennebique filed 17 patents in Belgium related to reinforced concrete between 1886 and 1912, those of 1892 and 1897 being the most important in paving the way for a relatively rational use of reinforcement in concrete (Hellebois 2013: 76).

From 1892, the enterprise of F. Hennebique took the form of a business office in Brussels where reinforced concrete structure projects were designed, which would then be realized by external companies. These companies were the *concessionaires* (or agents) of Hennebique's patents, and they paid Hennebique a royalty on the reinforced concrete work they carried involving placing the reinforcement according to the drawings from Hennebique's office. From 1892 in Brussels, Hennebique built up an international network of agents who spread the use of the "Hennebique system" of steel reinforcement of concrete constructions. In 1897, Hennebique relocated his business headquarters to Paris (Van de Voorde 2011: 47). His network of agents, supported by efficient promotion, became an empire, enjoying a virtual monopoly in the countries mentioned before, at least for a very large part of the reinforced concrete construction market up to around 1906 when scientific – and no longer empirical – methods of design began to be enforced in several countries with the publication of first official regulations.

In Belgium, the use of reinforced concrete in the last decade of the 19th century remained limited and was often restricted to floors and slabs (Hellebois 2013: 38). But abroad, the adoption of this new way of building had begun its spread earlier – especially in the 1880s in Germany – and many different (and incidentally not always very rational) reinforcement patterns began to appear. In fact, what characterizes this first era of reinforced concrete in the years 1880–1890 is the deployment of reinforcement bars governed by patents – and not, as is the case today, based on rational calculation methods. The patented methods were devised by self-taught inventors, architects and contractors, but rarely by engineers.

In 1899, a Belgian engineer, an official working in Brussels at the Central Administration of the Ministry of Public Works by the name of Paul Christophe (1870–1957), was delegated by the Administration to participate in the third Hennebique Congress in Paris (Hellebois & Espion 2013). By way of a report, he published in the *Annales des Travaux Publics de Belgique* in 1899 a very long paper which extended far beyond the subject of the conference and which aimed to be as complete an overview as possible of the current state of international reinforced concrete techniques (Figure 1.6.5), supplemented by formulas which he had devised himself for the rational design of reinforced concrete. Three years later, in 1902, Christophe published an expanded edition of this work in Paris in the form of a book (Christophe 1902). It is internationally recognized that this was the first scientific book dedicated to reinforced concrete, its use and design – as opposed to advocating a partisan or commercial point of view. It was translated into Russian (1903) and German (1905) and was widely plagiarized in Dutch (1902) and in English (1905). The method for calculating the main (longitudinal) reinforcement of beams and columns proposed by Christophe in 1899 was still widely used in many countries until the 1970s.

A major Hennebique system agent in Brussels in the early 20th century was the Louis de Waele company: using the Hennebique patent under licence, it built the extraordinary Royal Tour & Taxis warehouse (1903–1907) (Attas & Provost 2011: 72) with cantilever slab floors (Figure 1.6.6).

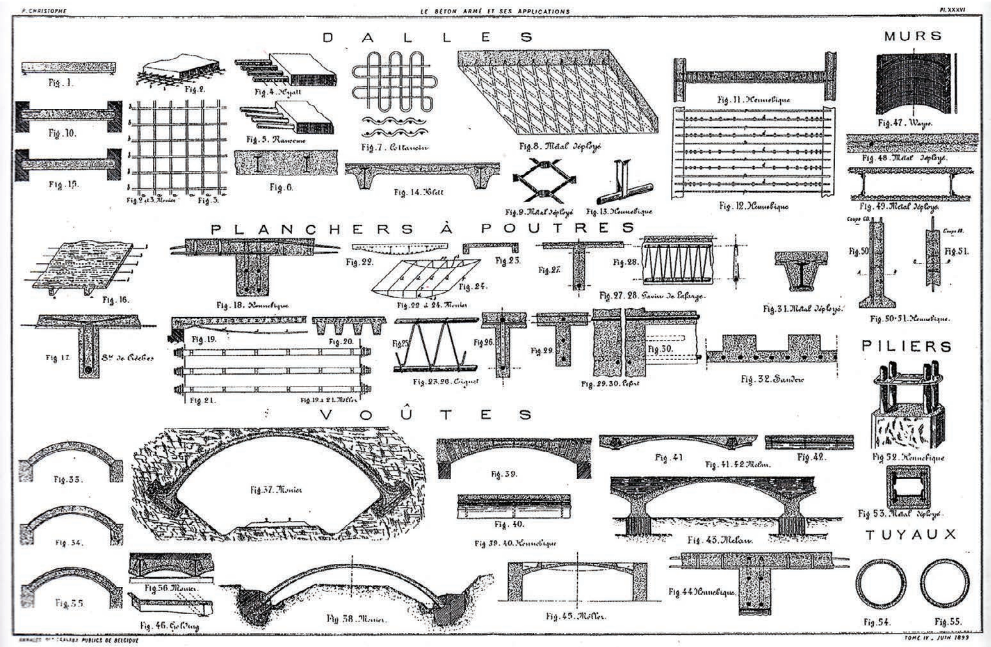

Figure 1.6.5 Overview by P. Christophe of existing reinforcement systems.

Source: Annales des Travaux Publics de Belgique, June 1899, pl. XXXVI.

Figure 1.6.6 Cantilever balconies in reinforced concrete at the Royal Tour & Taxis warehouse (1903–1907) in Brussels.

Photo credit: F. Romero for Wikimedia Commons, 2018.

Figure 1.6.7 The Mativa footbridge (1905) in Liège.
Photo credit: Jean-Luc Deru/Daylight.

But the best internationally known Hennebique structure in Belgium is the Mativa footbridge (Figure 1.6.7) erected as a publicity stunt for Hennebique, who wanted to build it as part of the World's Fair commemorating the 75th anniversary of Belgium (Denoël et al. 2013: 79–81). The contractor was the Hennebique licensee in Liège Maurice Prax (1872–1952). This footbridge, with a free span of 55 m, heritage listed in 2016, spans a canal (called the *Dérivation*) that diverts the outlet of the Ourthe River from the Meuse River.

The Blaton-Aubert company, which became Ciments et Bétons under the direction of Armand Joseph Blaton (1863–1929) from around 1890, embarked on construction using reinforced concrete in 1897 (Baes 1932: 652). At the turn of the century, the arrangement of reinforcing bars which it used closely resembled that of the Hennebique patent. The company, called Armand Blaton from 1905 to 1927, very rapidly became a general contractor for reinforced concrete, with a highly successful engineering office where engineers drew up plans for innovative projects plans using Christophe's calculation methods.

Any structure erected on the ground requires foundations. These may be spread footings if the soil layer near the surface has sufficient strength or is deep if required to find a solid with the suitable bearing capacity. The loads are then often transmitted by means of piles. Before the advent of reinforced concrete, piles were traditionally timber, driven into the soil with a mallet. With the advent of reinforced concrete, it became possible to prefabricate piles, which, like wooden piles, were driven into the ground by hammering. These had certain disadvantages, however, and very soon in the history of reinforced concrete, processes were developed to mould piles directly into the ground. In 1902, Hennebique began promoting a patented cast-in-place concrete pile invented by Dulac and called Compressol. Piles of this type formed the foundations of the Royal Tour & Taxis warehouse as well as those of the Mativa footbridge. In 1909, Edgard Frankignoul (1882–1954) from Liège, who worked with Maurice Prax in his Compressol company, filed a patent for what would become the Franki pile, and in 1910 he founded the Pieux Armés Frankignoul company, followed by the Compagnie Internationale des Pieux Franki in 1911 (Figure 1.6.8). The Franki pile quickly found success internationally with the establishment of subsidiaries abroad.

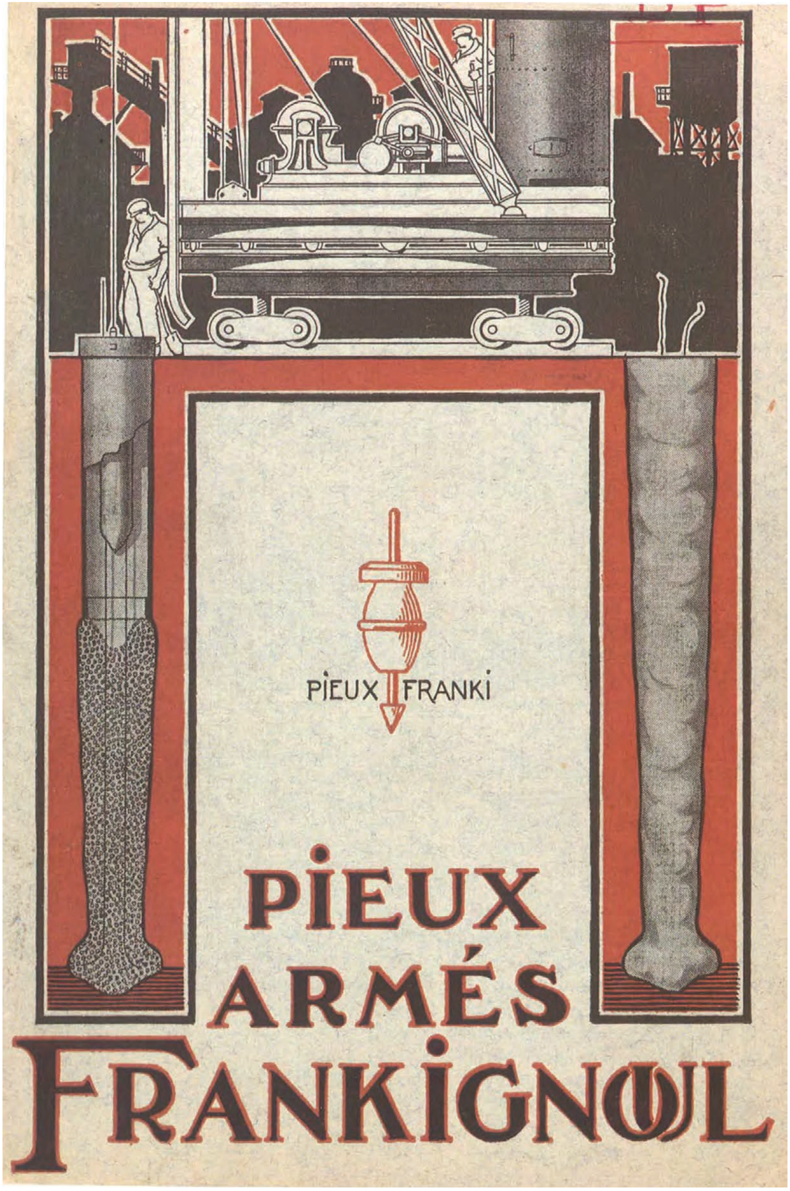

Figure 1.6.8 Franki advertisement from 1913.

Source: Dumoulin (1992: 38).

Reinforced Concrete Between the Two World Wars

On the eve of the First World War, reinforced concrete construction was already widely developed and streamlined. New types of structures and a new architecture emerged which took advantage of the characteristics of this material.

In the 1920s, reinforced concrete became ubiquitous in architecture, particularly with the appearance of apartment buildings and office buildings with a reinforced concrete framework. In the industrial sector, as well as in the field of infrastructure, its use became widespread in the construction of locks, quay walls, large viaducts and arch bridges. In Brussels, iconic examples of the use of reinforced concrete in the 1920s include the Palace of Fine Arts (1923–1926) by Architect Victor Horta (1861–1947) and the Grand Palais built for the 1935 Brussels International Exhibition (Palais 5) by architect Joseph Van Neck (1880–1959) and engineer Louis Baes (1883–1961), with its bold bearing structure composed of large three-hinged arches with an opening of 86 m (Baes 1937/38) creating an extraordinary area of free space (Figure 1.6.9).

The Franki company not only continued its international expansion as a specialist in foundation engineering but also developed a general contracting business in Belgium. For the construction of the National Basilica in Koekelberg (Brussels), which started in the early 1920s, Franki provided 1,438 piles between 1926 and 1929. The foundations of the Résidence Palace complex (1922–1927) were another flagship project for Franki in Brussels. In 1925, Franki launched a journal, *La Technique des Travaux*, which it continued to publish until 1977. The journal was originally intended to be a showcase for applications of the Franki pile, a little like Hennebique's magazine *Le Béton Armé* 25 years earlier. But it soon became established as a journal of high scientific and technical quality, publishing descriptions of reinforced concrete construction projects, both in building and in civil engineering, in Belgium and abroad. Although published only in French, *La Technique des Travaux* enjoyed an international audience; it is an excellent source – sometimes the only source, and certainly one of the most accessible sources – of documentation for concrete construction projects. It also published scientific studies on concrete and calculations for reinforced concrete (Van de Voorde 2011: 170–174).

The financial strength and international importance of the Franki company in the late 1920s are demonstrated by the fact that *La Technique des Travaux* sponsored the organization of the first international congress on reinforced concrete, held in Liège from 1 to 6 September 1930. Unlike Hennebique's congresses, this was a high-level, international scientific congress – the first in the field of concrete. It brought together mostly engineers along with some architects. All the leading names in reinforced concrete construction appear on the list of delegates at the conference, which constituted – undoubtedly for the first time – a gathering of the (primarily European) engineers who had been participating in the development of reinforced concrete construction since the beginning of the century. The final proceedings were published in 1932 by the publisher of *La Technique des Travaux*. They contain seminal articles, such as those written by the French engineer Eugène Freyssinet (1879–1962) on his studies of time-dependent deformation of concrete and by the German engineer Franz Dischinger (1887–1953) on thin concrete shells. Today, the design of concrete structures is governed by unified codes, at least at the European level: the same philosophy, the same concept of safety and the same calculation models apply in all European countries. That was certainly not the case in the 1920s. It is appropriate to emphasize the foundational importance of the congress at Liège in 1930 for the exchange of ideas and national achievements in the field of reinforced concrete.

From an international perspective, the most outstanding achievements by Belgian engineers and companies in the field of reinforced concrete bridges during the 1930s were in Katanga: the

Figure 1.6.9 Interior of the Great Hall (Palais 5) of the 1935 Brussels International Exhibition.
Source: Photo credit: Ch. Bastin and J. Evrard.

Figure 1.6.10 Closing in August 1939 of the largest span (70 m) of the Kongolo Bridge.
Source: Collections of the Africa Museum, Tervuren.

railway bridges over the Lualaba River (1937–1939) and the Lukuga River (1938–1939), both of which were constructed by Trabeka, a Brussels-based company specializing in concrete construction in Congo since 1924 (Espion & Provost 2021). The crossing of the Lualaba River at Kongolo, Democratic Republic of the Congo (Figure 1.6.10), is a remarkable early implementation of the construction of a multiple-span concrete viaduct using a travelling gantry supporting movable formwork, and the crossing of the Lukuga River can be considered the oldest existing concrete bridge in the world built using the cantilever method (Espion et al. 2015).

Prestressed Concrete

Although one can find numerous attempts to pre-stress concrete from the beginnings of reinforced concrete, it was the French engineer Eugène Freyssinet (1879–1962) who filed the first patent for the efficient production of prestressed concrete elements in 1928 and developed its first applications in the 1930s. These, however, remained very limited – or confidential – before the Second World War. In 1939, Freyssinet completed the development of technology to achieve prestressing by post-tensioning: tendons, anchorages and jacks for tensioning cables – all patented devices.

Professor Gustave Magnel (1889–1955) of the University of Ghent was the first engineer in Belgium to take an interest in prestressed concrete. In 1941, he devised an experimental or prototype structure: a 20-metre span railway bridge deck to support the railway tracks of the North-South junction above *Rue du Miroir* in Brussels.[4] Initially, Magnel considered using the technology patented by Freyssinet to perform the work. In November 1941, Freyssinet emphasized this in a lecture he gave in Paris: "Professor Magnel of the University of Ghent [. . .] is helping me develop applications for prestressed structures in Belgium" (Freyssinet 1941: 341). But the war made it impossible to import Freyssinet's technology into Belgium. Magnel did not give up, though, and he began to develop a close partnership with the Blaton-Aubert company, which went on to construct the bridge, thereby developing a "Belgian" technology for prestressed concrete utilizing *post-tensioning* inspired by Freyssinet's ideas.

> We began to take an interest in the problem in 1941, and we had the good fortune to be able to do it in collaboration with a large contracting company in Brussels [i.e. Blaton-Aubert]. [. . .] After numerous attempts, we managed, in collaboration with our contractor, and without it being possible to determine from the final result what the contribution of each had been, to develop a cable with accessories and a device for establishing the prestressing. This is the sandwich cable which Belgian specialists now know very well and which, with only one exception, is the only type which has been utilized on-site in Belgium to this day.
>
> (Magnel 1948: 178; translation by the author)

For ten years (1941–1951), the collaboration between Gustave Magnel and Blaton-Aubert proved particularly rich and fruitful, not only in Belgium but also internationally (Pesztat et al. 2017: 76–87).

The construction by Blaton-Aubert of railway bridges at Rue du Miroir in Brussels provided the opportunity in July 1943 to perform a full-scale load-to-failure test on a 20-metre span prestressed concrete beam, which splendidly validated the "sandwich" technology (also known later as "Blaton-Magnel"). From that point onwards, the way was open for Magnel and Blaton-Aubert to promote the applications of prestressed concrete in Belgium. During the war years, and even more after that, during Reconstruction, prestressed concrete was able to compete effectively with reinforced concrete because it consumed less steel, less concrete (and thus less cement), less timber formwork and centring and allowed more rapid construction with the use of prefabrication. So, it was very competitive. The necessarily innovative applications of prestressed concrete devised in Belgium from 1943 onwards by Blaton-Aubert and other Belgian companies using the sandwich technology were many and varied. Some noteworthy applications in Belgium received particular attention in the foreign trade press (Espion et al. 2018):

- the aircraft hangar roofs at Zaventem (currently still in existence in the technical zone of Brussels International Airport),[5] with 51-m span beams each weighing nearly 300 tonnes (1948);
- the roof (35,000 m^2) of the Union Cotonnière (UCO) mills in Ghent, which uses a system of primary beams (100 beams with a span of 20.8 m) supporting secondary beams (600 beams with a span of 13.6 m); built in 1948, largely demolished (with a few parts preserved) in 2017. It is important to emphasize the major, global innovation in the typology of structures which was made possible by the use of prestressed concrete beams (Figure 1.6.11);
- the Sclayn bridge over the Meuse (1949–1950), the first two-span continuous beam bridge in the world in prestressed concrete, each span measuring 63 m.

Based on his experience, Magnel published a book in 1948, in French and in English, on the design of prestressed concrete. This was the first major book on the subject, and it aimed to be didactic, practical and scientific. Given its success, it was reprinted (and was also translated into German and Spanish), the third and last edition appearing in 1954 (Magnel 1954); it details all projects in prestressed concrete in which Magnel was personally involved. Today, civil engineering students all over the world still learn about the "Magnel diagram" for the design of prestressed concrete beam sections, as it continues to be relevant to their education.

Figure 1.6.11 Construction of the *Union Cotonnière* mills buildings in 1948.
Source: Blaton Archives, Fondation CIVA.

After the end of the Second World War, Magnel and the Blaton-Aubert company turned their attention to trying to export the sandwich system. Their first notable successes were in Britain, where the Freyssinet system was already known. But, most notably, the Belgian sandwich technology was chosen for the construction of the first prestressed concrete bridge in the USA: a bridge at Walnut Lane in Philadelphia (1949–1951). On 25 October 1949, Magnel directed an on-site loading test up to failure on a sandwich-type prestressed concrete beam with a span of 47 metres in the presence of over 300 engineers from around the world. The resounding success of this test established Magnel as an international authority in the field of prestressed concrete, especially in English-speaking countries. Backed up by this international recognition, Magnel organized the First International Congress on Prestressed Concrete in Ghent, from 8 to 13 September 1951, in which Freyssinet received the insignia of doctor *honoris causa* from the University of Ghent. The International Federation for Prestressing (FIP) was created in 1952: Freyssinet was the first chairman and Magnel the first vice chairman.

Thin Concrete Shell Structures

At the international level, another great innovation in the field of concrete construction which, historically, was developed alongside prestressed concrete – and often by the same people – was the use of thin concrete shells for long span roofs without inner supports, as an alternative to steel structures. Their story began in Germany back in the 1920s with barrel vaults promoted by Dyckerhoff & Widmann with its patented Zeiss-Dywidag (Z-D) construction system, and in France with conoïdal shells and hypars (Denoël et al. 2013: 117–122). The Franki company was already serving as the Belgian representative for the patented Z-D system before 1930 and used it at least twice for industrial plants in Belgium.[6] The very first international conference on thin concrete shell roofs was held in London in 1952, and the only non-British contribution to the conference was a presentation of barrel-vault warehouses covering 5,000 m^2 at the Port of Antwerp, built by the Brussels-based SETRA company between 1947 and 1950 (Espion et al. 2003). The technical director of SETRA at that time was engineer André Paduart (1914–1985), who became a professor at the University of Brussels (ULB) in 1954. Among the structures that could be described as applications of thin concrete shells built in Belgium (and there are not many of them), all those which received international attention are very unusual, a far remove from "traditional" applications of thin shells.

In 1947, the Blaton-Aubert company built two circular hangars for light aircraft in Grimbergen. Each hangar was covered by a concrete shell in the form of a large dish plate, 50 m in diameter, placed on four concrete pillars (Figure 1.6.12). The idea for this structure came from a self-taught inventor, Alfred Hardy (1900–1965). Very few buildings of this type were constructed. It became well-known partly for this reason and also because it was included – as the sole Belgian entry, moreover – in the catalogue of an exhibition dedicated to 20th-century

Figure 1.6.12 Circular aircraft hangar at Grimbergen, 1947.

Source: Blaton Archives, Fondation CIVA.

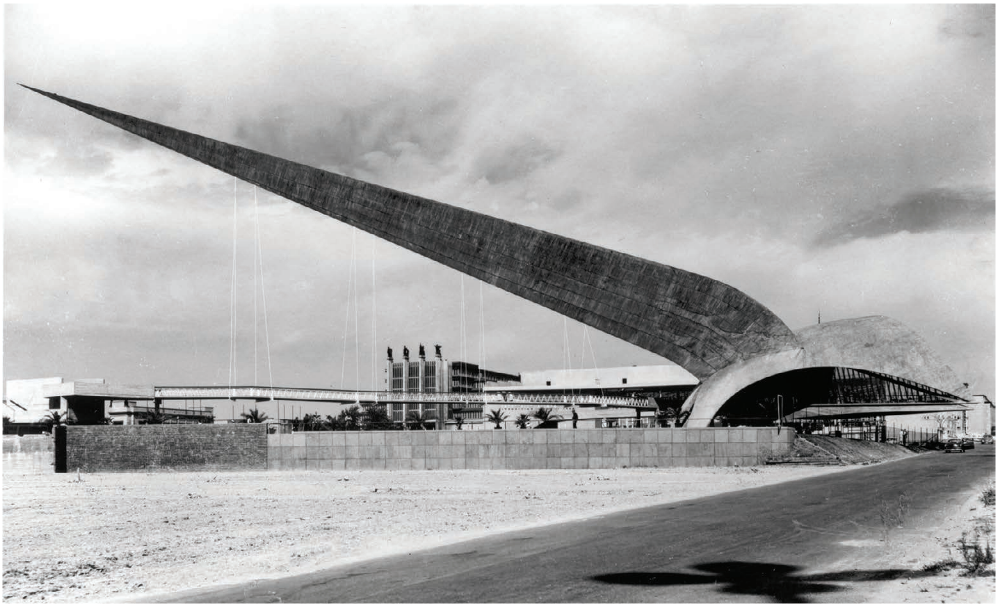

Figure 1.6.13 Civil Engineering "Arrow" at Brussels World's Fair 1958.
Source: SETESCO.

engineering and construction held at the Museum of Modern Art in New York in 1964 (Espion et al. 2018).

At the Brussels World's Fair in 1958, two thin concrete shell structures, also atypical, attracted attention. One was admired for the boldness of its construction: the Civil Engineering Arrow (Figure 1.6.13), a huge folded plate cantilever of 80 metres, created by the trio of engineer André Paduart (1914–1985), architect Jean Van Doosselaere (1919–2000) and sculptor Jacques Moeschal (1913–2004). This structure received a Construction Practice Award from the American Concrete Institute in 1962 (Paduart & Van Doosselaere 1960). It was demolished in 1970.

The other thin shell structure that made a big impression was the Philips Pavilion by architects I. Xenakis and Le Corbusier. It was an assembly of hypar segments (Xenakis et al. 1958). However, unlike the thin hypar shells of the time, the shells were not cast in place but were the result of the assembly of precast skew tiles, held in place against each other by prestressing. The pinnacle of thin concrete shell roof construction falls in the late 1950s, when, belatedly, the *International Association for Shell (and Spatial) Structures (IASS)* was created in 1959; André Paduart was a founding member of the *IASS* and would later serve as its (third) chairman from 1971 to 1980 (Espion et al. 2003).

Conclusion

In this chapter, we have highlighted the outstanding Belgian contributions to the international history of concrete and concrete structures, which can be summarized as follows:

- the French pioneer of reinforced concrete, François Hennebique, began to build his international empire from his base in Belgium in the 1890s;

- it was the Belgian engineer Paul Christophe who in 1902 wrote the first book on the rational design of reinforced concrete, which formed the basis for the calculation methods used universally until the 1970s;
- the Franki company, based in Liège, played a leading role internationally in the development of foundation techniques and published the journal *La Technique des Travaux*;
- the major role of Professor Gustave Magnel of Ghent, in association with the Brussels-based company Blaton-Aubert, in the development and promotion of prestressed concrete.

These situations, these contributions and these companies have had a fundamental impact on the history of construction.

Notes

1 This is actually Andernach trass, a volcanic tuff from quarries at Andernach in Rhineland; nowadays, this material would be considered as a kind of natural fly ash.
2 The dam was raised by 17 metre between 1967 and 1970 and is now completely buried inside a rockfill dam of which the original masonry dam forms the core.
3 The annual production of Portland cement in Belgium was only 80,000 tonnes in 1884 and 150,000 tonnes in 1896 (Dutron 1948: 162).
4 Today, this part of the street covered by the bridge decks is called the Rue Roger van der Weyden.
5 The author is indebted to I. Anderson who indicated to him that these hangars are still standing.
6 Roof of the Forges de la Providence coal yard at Marchienne-au-Pont and shed-silo at the UCB factory in Tertre (see Baes, p.774 and p.889; this shed still exists).

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Chapter 1.7

Reinforced Concrete in Italy

From Its Origins to the Second World War

Tullia Iori

Introduction

This study summarizes the results of a research project which addressed a range of issues regarding the development of reinforced concrete in Italy. How did this new technique begin to spread at the end of the last century? To what extent was this new technique imported from abroad? And how did foreign systems spark its autochthonous development?

Based on sources from the Patents Office Archives and specialized engineering magazines barely utilized before, this study reconstructs the use of reinforced concrete in construction work in Italy from its first applications up to the Second World War. The study focuses on a sequence of more than 1,000 inventions, both Italian and foreign patents, which determined the many formulations and subsequent revisions of this technique. It attempts to bring order to a vast debate on the structural theories and calculation methods, also employed in Italy, which accompanied the development of reinforced concrete.

The Advent of a New Technique (1850–1900)

Between 1850 and 1900, experiments were conducted both in Europe and in the USA with the use of a new material created by combining two very widely employed industrial products: cement and structural iron. This new material was called *béton armé* (reinforced concrete).

How Was Italy Involved in This Experimentation?

Construction techniques in Italy were certainly unique. Although the general lag in industrialization – and, in turn, in the iron and steel industry – had not completely blocked the development of iron architecture, it had certainly slowed it down. Construction work, however, was undergoing an interesting period of evolution after many centuries of relative standstill. In Piedmont, in particular, Alessandro Antonelli (1798–1888) rationalized reinforced masonry in bold interventions on different monuments. Cement, which was just beginning to be produced on an industrial scale at this time, was exclusively used for decorations and finishes through a technique known as *cemento artistico*.

In fact, Italy did not directly participate in the pioneering experimentation phase of what was referred to as *béton armato*; nonetheless, the construction industry was very interested in this new development. Thus, the most important patents protecting this technological improvement were also deposited in Italy, although the dissemination and application of the new techniques were much slower.

DOI: 10.1201/9781003368656-9

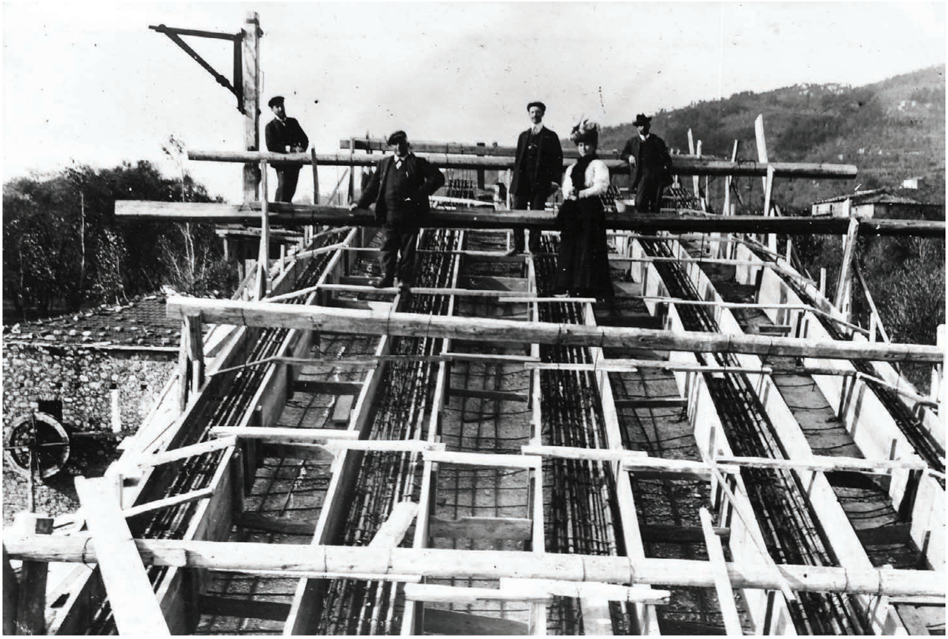

Figure 1.7.1 Attilio Muggia (1861–1936), a Hennebique agent in central Italy as of 1897; bridge over the Magra River at Caprigliola and Albiano, 1903–1908.

Source: Nino Ferrari private archive.

François Hennebique (1842–1921), a shrewd entrepreneur holding an innovative patent, played a key role in the spread of this new material – especially in Italy, where he set up a very efficient series of branch agencies (Figure 1.7.1).

Meanwhile, the increasingly daring applications of reinforced concrete in Europe set off an animated debate – primarily involving French and German scientists, who focused on the formulation of a less empirical "rational" calculation theory for the new material than those previously produced by the patent owners.

The importation of foreign systems led to widespread experimentation, which soon involved the entire local enterprise system. By the mid-1890s, a vast number of local patents had been deposited that were often sophisticated variations of tried-and-tested foreign systems.

The application of these new techniques was not limited to the leading construction firms that had quickly converted to the new technology. Newly created companies specializing in the use of reinforced concrete construction were also quick to make the most of the new development. The number of buildings and monuments created, both with Italian and foreign patents, right before the turn of the century demonstrates the interest of local enterprises in this new material and its unstoppable spread.

Diffusion (1900–1915)

By the turn of the century, the pioneering period of reinforced concrete had come to an end both in Italy and in Europe. It was officially recognized as an invaluable material and was commonly used in construction work.

The new construction technique became part of the professional training of engineers. Manuals were published that addressed the main issues related to the use of reinforced concrete and established basic procedures and standards for its application. In universities, science and mechanical construction courses embraced the technique, and graduates were finally equipped with the information necessary to safely apply the various systems.

At the same time, mainly due to many persisting computational uncertainties, the increase of unmanageable construction systems and the collapse of buildings under construction, many European countries adopted a series of cautionary measures which evoked further debate. In Italy, the Ministry of Public Works approved a series of regulations governing reinforced concrete construction work to guarantee the safety of public works.

However, the diffusion of the new material and its widespread use in the construction of residential buildings and public infrastructures required a new national law. In the many new technical magazines dedicated exclusively to reinforced concrete construction work, the thousands of structures erected by Hennebique agencies were reflected in the applications of the numerous specialized construction companies in constant competition with one another.

In the meantime, once the framework-concrete mechanism had been firmly established, patent experimentation turned to individual construction elements and in particular floor construction techniques, in which reinforced concrete was used to replace traditional construction methods. The new inventions showcased the first prefabricated beams and the first hollow bricks for the construction of block and beam floor systems, which were soon to undergo an extraordinary development in Italy.

A decisive stimulus for the definitive establishment of the reinforced concrete technique came in the aftermath of the 1908 earthquake in Messina and Reggio Calabria. By the 1920s, the anti-seismic framework was widely implemented, profoundly conditioning the way in which reinforced concrete was employed in Italy.

Meanwhile, the classic computation theories – which had gradually been perfected – were employed in the erection of large works. The Ponte Risorgimento (Figure 1.7.2), a bridge

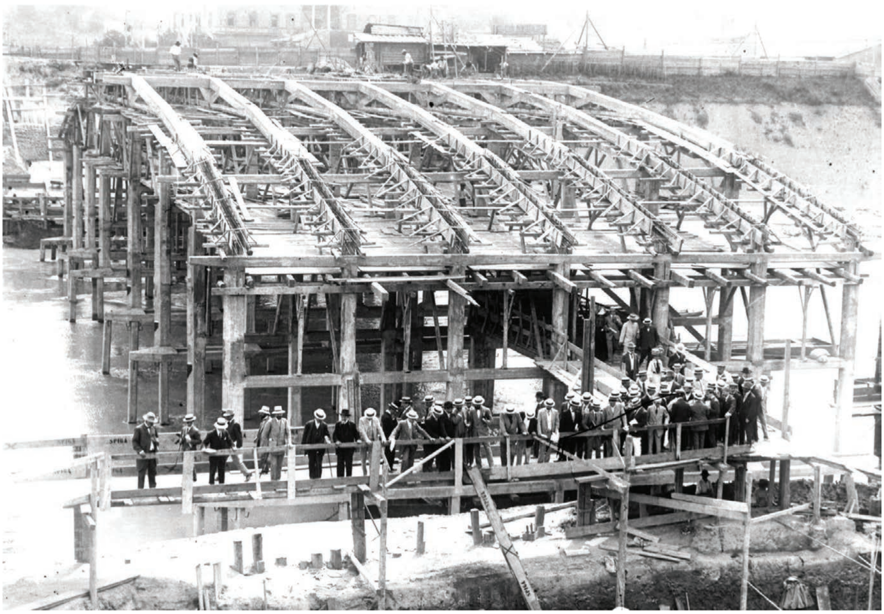

Figure 1.7.2 Risorgimento bridge, construction site, 1911.

Source: G.A. Porcheddu Archive, Turin Polytechnic.

erected in Rome in 1911, was to influence many of the theoretical debates of the coming years. It played a key role in comprehending the limits of the elastic behaviour hypothesis of reinforced concrete.

Standard Use of Reinforced Concrete (1915–1935)

As of the post-war reconstruction and throughout the 1920s, reinforced concrete became a common construction technique.

In this phase, characterized by the erection of public residential buildings, this construction system – which proved faster and cheaper than traditional systems – turned out to be perfect and was often used together with load-bearing masonry in a mixed system.

The reinforced concrete technique was no longer the exclusive domain of patents and specialized firms. It had become part of mainstream professional engineering and was employed by many small and medium-sized companies. And to simplify the work of neophytes and expedite expert projects, (not always rigorous) manuals, abacuses and charts became readily available along with new mechanical tools such as slide rules and the first calculators.

The fact that this technique became increasingly accessible to companies and project designers who were not necessarily qualified called for a more scrupulous application of the existing laws and, in particular, the regulations regarding executive project aspects. The outdated law issued in 1907 was reviewed in 1927 and extended to apply to all construction work, both public and private.

Figure 1.7.3 Pier Luigi Nervi; stadium in Florence, 1931.

Source: Touring Photo Archives, Milan.

Meanwhile, the scientific community continued to study the material and refine their knowledge of previously unexplored parameters. Industry continued to improve and transform production techniques, privileging artificial cement over natural cement, which had grown scarce. This process of refinement led to the invention of special-use cements.

During the latter half of the 1920s, a series of circumstances drastically changed the course of Italian construction techniques. And the role of reinforced concrete changed, too. Within just a few years, the Fascist regime had drawn the construction sector back into a state of corporatism. The reaction to the great crisis of 1929, which interrupted the development of construction work, spawned the development of new techniques. Moreover, this all took place concomitantly with the beginning of the great debate on modern architecture.

What role did the reinforced concrete technique play in this transformation process? And how did that technique evolve as a result of this transformation?

While technological experimentation was directed towards large structural works, research looked at the shape of reinforced concrete frameworks in relation to the search for new forms and worked towards defining a new architectural language. Construction methods evolved rapidly, encompassing architectural culture. The results of this phase can be witnessed in the works carried out in the first part of the 1930s, by great engineers like Pier Luigi Nervi (1891–1979), before the autarchic period changed conditions once again (Figure 1.7.3).

Autarchic Experimentation (1935–1943)

The Italian aggression in Ethiopia and the subsequent economic sanctions raised against Italy by the Society of Nations in November 1935 gave rise to a critical phase in the economic policy of the Fascist regime. The protectionist orientation aimed at making Italy self-sufficient (a key element of corporatism) became increasingly stringent and led to the most intense phase of autarchy, which was also boosted by subsequent military decisions.

In construction work, as in all other productive sectors, the objective of becoming independent from all imported material became a determining factor. This not only sparked a fierce debate but also increased the range of experimentation aimed at finding new solutions with a greater "national value". The use of reinforced concrete was dependent on foreign supplies both for the wood used for the moulds and for the framework iron, so the technique was accused of being anti-autarchic. Even though the "gold-cost" ratio revealed that it was more convenient than other building techniques (using steel or load-bearing masonry), the need to reserve all iron for the military effort led to it being controlled. Thus, the use of reinforced concrete became severely limited from 1937, and by 1939 it was completely banned.

But the restrictive measures did not stop engineers and researchers, who continued to study ways to make reinforced concrete more "autarchic" under two main lines of research.

A more "traditional" line of research adopted a long-term approach and hypothesized that once the war was over, the use of reinforced concrete would pick up again with nationally produced iron. This research, then, aimed at economizing the use of iron in frameworks by employing higher precision calculation methods, more meticulous design work and the use of materials with higher performance potential (high-resistance cement and steel).

The other line of research – which was more innovative and aimed at obtaining immediate results – returned to the experimentation that had been carried out right after the war, when supply problems and the high cost of traditional building materials had fuelled research on alternative, nationally available materials. As had already been proposed during the period of "building frenzy", wood and new materials, such as bamboo, asbestos-cement and aluminium, were proposed as possible materials for building the frameworks. In order to reduce dead loads in buildings, the use of cement blocks and perforated bricks was increased together with pumice-based elements and materials composed of other waste products.

A law was also passed to allow the construction of mixed-element floors without slabs, and horizontal construction methods with reduced frameworks were studied. As the lack of framework iron increased, experimentation turned to constructing floors without steel. From the Eugenio Miozzi (1889–1979) patent to the Giorgio Neumann patent, dozens of systems based on the traction resistance of bricks and cement claimed to achieve structurally safe flooring systems without the use of steel. This final phase of research, which was abandoned right after the war, often provided unexpected results that were not justified either by calculation or material characteristics.

Major Works (1920–1943)

Starting in the mid-1920s, as we have seen, reinforced concrete gradually became an everyday construction material. The innovative turmoil that had accompanied the development of this material shifted from construction elements to application methods as part of the renewed building conception that progressively led to a complete transformation of the existing relation between load-bearing masonry and framework.

So, what was happening in the major works sector? In order to answer this question, we have to step back to the beginning of the 1920s and follow the experimental course of the building techniques relevant to structurally important works.

Manuals and experience were sufficient to erect normal reinforced concrete buildings; technological and theoretical experimentation was directed at larger structures. In fact, this was what interested the specialized firms, which left ordinary construction work to the many small companies that had blossomed to instead concentrate on projects in which accumulated experience was indispensable. The most recent industrial and theoretical inventions, from high-performance artificial cement to building site machines and from sophisticated frameworks to intricate calculation theories, were applied to these major projects (Figure 1.7.4).

Starting in the mid-1930s, the Fascist regime's economic policy condemned the use of the scarcely available autarchic reinforced concrete and eventually forbade its use in both public and private civil constructions. However, if this ban had been rigorously applied to the major works sector, the building sites would have ground to a complete halt. In such cases, the projects were reviewed to minimize the use of iron. Resistance values of materials were arbitrarily increased, and isostatic structures were employed to allow precise calculations and, as a result, optimal member use. Meanwhile, a process of involution set in: bearing distances diminished, and the use of reinforced concrete shifted to "less reinforced" concrete and then to simple concrete. Finally, *forte sesto* arches were rendered in traditional masonry as it was considered more autarchic.

Although autarchy brought about an involution of practical applications, it also stimulated research into rational structures, which, according to the fundamental principles of structural engineering, also meant less expensive structures. Old solutions that had been put forward in the pioneering phase of this material resurfaced in opposition to attempts to substitute or eliminate iron as new technological developments (new cements, special steels) and an increased knowledge of these materials (cement traction, framework release and viscous phenomenon) allowed techniques to be fully developed.

Figure 1.7.4 Pier Luigi Nervi, "Second series" Hangars, Orbetello, 1939–1942.
Source: Maxxi Architecture Archives, Pier Luigi Nervi collection, Rome.

The objective of autarchic experimentation was to radically transform the relation between iron and cement and overcome the intrinsic limitations of reinforced concrete. This research followed two routes.

One route was represented by the thin structures that began with the cemented iron and European research on vaults and shells by Joseph Lambot (1814–1887) and Joseph Monier (1823–1906) and later led by Pier Luigi Nervi (1891–1979) to experiment on highly reinforced reduced thickness structures. This led Nervi to invent *ferrocemento*, a new homogeneous, isotropic and elastic material that would characterize his entire post-war production (Figure 1.7.5).

The other route also led to the creation of a new material, which was erroneously called "precompressed reinforced concrete" in Italy. Research conducted at the beginning of the century was used to invert the role of the two basic materials of reinforced concrete: iron no longer had to absorb the traction that the cement could not support, but became the means to impress the conglomerate with the necessary constraint to absorb all the stress.

A lively debate flourished in Italy regarding the far more efficient experiments conducted in Europe by Eugène Freyssinet (1879–1962), Franz Dischinger (1887–1953) and Ulrich Finsterwalder (1897–1988), which led to important theoretical contributions such as those made by Gustavo Colonnetti (1886–1968). In the years preceding the war, he set the premises for important developments that were to be widely used during the reconstruction period and which were to bring about international recognition for another Italian engineer, Riccardo Morandi (1902–1989).

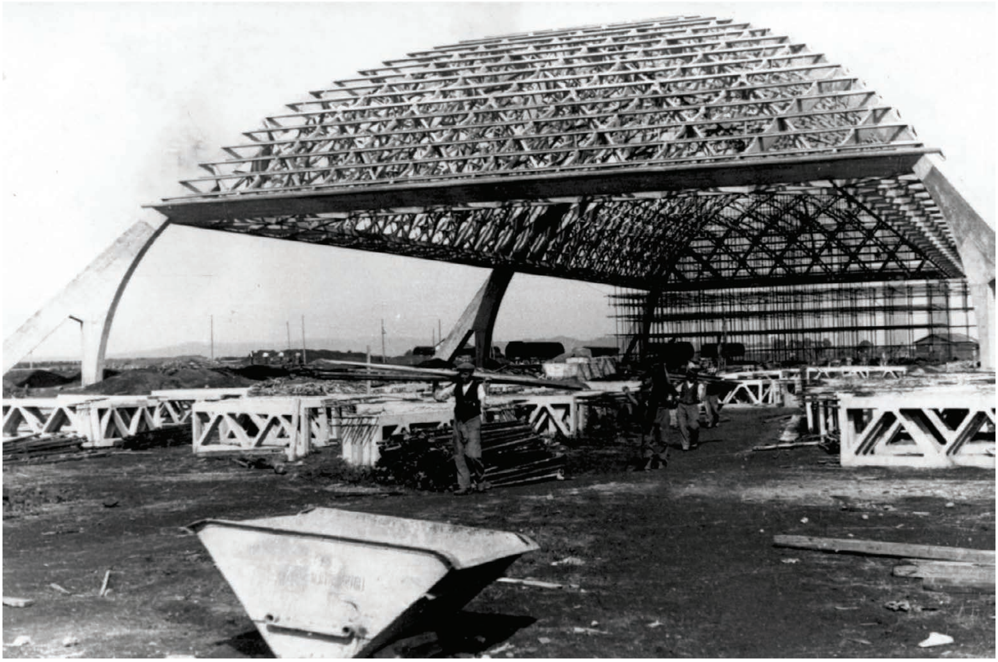

Figure 1.7.5 Pier Luigi Nervi, Magliana Pavilion, Rome, 1944–1945.

Source: The author. Photo credit: Sergio Poretti.

Conclusion

This study was developed under the guidance of Sergio Poretti (1944–2017) during the three years (1997–1999) of a PhD research project entitled “Architecture and Construction” at the Doctoral School of the Tor Vergata University of Rome. The research was published in 2001 in a book included in the “Il modo di costruire” series and won the second Edoardo Benvenuto Prize.

This study was part of a larger research project, conducted by Sergio Poretti and the author, named SIXXI (Twentieth Century Structural Engineering: The Italian contribution), funded by an European Research Council Advanced Grant 2011.

The general goal of the research was to give a major contribution to the international history of the role of engineering in architecture. The research project focused on the works and protagonists of 20th-century structural engineering in Italy.

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Part 2

Actors of Change

Public Works Contractors and the Construction of Modernity

Chapter 2.1

British Public Works Contracting, 1730–1880

Mike Chrimes

Introduction

In 1957, Harold Pollins observed: "The contractor is an elusive figure in the history of British railways" (Pollins 1957–1958). If he had described the canal contractor of an earlier, era he might well have said "invisible", and much the same could be said today about many elements of public works contracting at that time. This chapter will outline the main developments in public works contracting in the period 1730–1880 in Britain and Ireland, informed by research over the last 65 years. The opening date allows some discussion of the state of contracting on the cusp of the canal age, and the closing date marks the passing of most of the great early railway contractors at a time when the scale of British overseas investments was about to grow enormously, while municipalization at home was to offer new opportunities for the contracting entrepreneur (Ferguson & Chrimes 2014; Floud et al. 2014; Cain & Hopkins 2016).

Bearing in mind the traditional toast of the 18th-century Smeatonian Society of Civil Engineers "To waterworks, public and private", it should be stressed that much of the work of the contractors of that era was privately financed, or for some form of trust, for example turnpike roads, rather than being linked to publicly owned enterprises. Central government was certainly important for funding defence projects, and some civil infrastructure works such as roads in Scotland and Ireland, but the enabling legislation that allowed local authorities generally to provide gas and water supply and meaningfully deal with urban sewage was the result of municipal reforms through the 19th century, and the great era of municipalization actually came after the period under consideration. This chapter will also not say much about building contractors, the focus being on contractors working on civil engineering projects. One could argue that this is something of an artificial distinction, as contractors were in it for the money, either to make a living or, in some cases, to make a fortune, and would as happily build a church as a bridge or a housing estate as a railway line – and many did, as well as investing in mines, mills and publishing businesses. With regard to the value of money, contemporary values are given throughout, the very different modern equivalents are best obtained through the Measuring Worth website and reading the earlier discussion by Skempton et al. (2002; Measuring Worth).

It is intended to give some sense of the scale and variety of contracting businesses and remind researchers of the need for a holistic approach. The appeal of construction history is often stimulated by a sense of awe at seeing the final product of the construction process. The success of that process is generally dependent on the financial credit of the public works contractor, which will in part derive from the diversity of their portfolio of assets. In the period under consideration, we are talking very much about individuals and families, whose interests outside construction may be obscure today. Pollins' elusivity stemmed in part not only from the limited number

DOI: 10.1201/9781003368656-11

of biographies available, and their hagiographic nature, but also from the shear amount of time and effort required in identifying contractors of the past through archives, local newspapers and specialist journals and the general absence of business records for well-known figures. One of the best-known contractors of the railway age, Sir Samuel Morton Peto (1809–1889), has been the most studied in recent years; yet no single biography can be regarded as definitive (Brooks 1996; Cox 2008; Peto 1893; Sparkes 2013; Vaughan 2009) Digitization programmes have helped with access, but not the volume of material that has to be reviewed. The hard work that Jenks put in a century ago on British overseas investments has yet to be superseded in terms of trawling through the railway press (Jenks 1963; Cottrell 1975a: 13, 70). However, a broad picture can still be painted of the rise of the general public works contractor.

Contracting in the Early 18th Century

It is more than 60 years since E.W. Cooney identified four broad types of building firms as a means of studying the evolution of the construction industry through the 18th and early 19th centuries (Cooney 1955). These were *master craftsmen* practising only in their own trade, that is carpentry, masonry and so on; *master craftsmen* undertaking an entire building but only employing workers in their own trade and using other masters to supply workers in their craft specialisms; *builders*, perhaps timber or stone merchants, or (self-styled)-architects undertaking perhaps the design and construction of an entire building, but using contracts with master craftsmen to provide the labour; and *master builders* who both took on complete buildings and employed staff in various trades. In general, prior to the late 18th century, one only finds the first three categories of contractor and generally only the first two. The classic example of the latter – who did not emerge until the early 19th century – is Thomas Cubitt, a master carpenter who in the decade 1815–1825 developed a business with his brother William from undertaking (large) individual buildings and houses, to that of a speculative urban developer, directly employing perhaps 700 workers (Hobhouse 1995).

More recently, Bertels and other researchers in Belgium and Wermiel in the USA have used a similar approach as a starting point for their analyses of the rise of general (public works) contractors (Bertels 2011; Bertels et al. 2011; Wermiel 2006). Interestingly, Wermiel saw the term general contractor as first applied in civil engineering and public works and later to builders, and in the UK, general civil engineering/public works contractors operating on a national scale predate Cubitt's enterprise.

The key to the emergence of general contractors must have been a volume of work justifying the investment in a large workforce and plant with a reasonable chance of a good return on the capital employed. There was also an issue of client trust in the contractor and their skills and experience to undertake complex or specialist work across wide geographic areas. Prior to the 18th century in the British Isles, such work would have been the prerogative of the State, the Church (Figure 2.1.1), some members of the aristocracy and some wealthy city merchants, often only conducted by direct labour.

While Holzer (2021) has demonstrated how much can be found out about construction methods of the medieval and early modern period, when examining the contractors using such equipment, we are confronted with the situation to be found in many European art galleries: a room full of portraits entitled "unknown gentleman". This is not to say nothing is known; we often have names, and for the UK, some well-researched works have been published, which cast light on the civil engineering and construction works of the period (Binnie 1987; Blair 2014; Chalkin 1998; Harrison 2004). For the period after 1500, an attempt has been made to record some contractors where enough could be found about their lives and works (Skempton et al. 2002).

Figure 2.1.1 Valle Crucis Abbey and fishpond – a typically remote Cistercian Abbey built and modified in 1200–1500 under the leadership of a number of generally Welsh abbots and the patronage of Welsh princes. A carving on the 14th-century west front, in the background, credits Abbot Adam with its construction, but there are no other clues as to the masons and carpenters involved.

Source: The author.

Unsurprisingly, there is evidence of large-scale enterprises in London in the aftermath of the Great Fire. The Fitch brothers – Sir Thomas (1637–1685) and John (1642–1706) whose family was probably involved in the Hertfordshire brick trade – can certainly be regarded as general contractors with a national reach. As well as country houses and prestigious London buildings, they worked together on the Fleet Canal after the Fire. Thomas worked on fortifications at Portsmouth and Hull and advised on the rebuilding of Denver Sluice; John worked under him and alongside him on the Fleet, and at Portsmouth and elsewhere, as well as carrying out two docks at Portsmouth, buildings at Plymouth Dockyard (at a time of major capital investment in the Navy) and Chatsworth and Buckingham houses.

Elsewhere, one can see all kinds of expertise and project organization prior to the 18th century. Matthew Hake was employed as contractor on Boston Sluice (1500–1502). He was brought in from Gravelines, France, presumably because the scale of the work was seen to be beyond the expertise of local carpenters and masons. Such employment of "foreign" experts was common before the mid-18th century. John Trew (fl. 1563–1588) came from a mining background, but offered his services as a design-and-build contractor on the Exeter Canal, Waltham Pound Lock on the river Lea and on Dover harbour pier, with mixed success. The difficult and ultimately highly costly scheme to create a breakwater at Tangiers, which came into English possession following the marriage of Charles II to Catherine of Braganza, is an atypical case study because of its scale and its overseas location (Figure 2.1.2).

It was decided that a sheltered harbour was required to provide safety from storms and Barbary coast pirates. The initial contract (1663) for the breakwater construction was with a design-and-build consortium comprising Sir Hugh Cholmley as "engineer", the naval commander Sir John Lawson and the Governor Lord Teviot. The deaths of Cholmley's partners and technical difficulties led to a different approach using direct labour under the military engineer Sir Henry Shares, notable for the use of chests of pozzolanic concrete, after an offer by Thomas Fitch among others to complete the work by contract was turned down. The work was ultimately abandoned and destroyed in 1683, at a cost of £380,000.

There was work in bridge maintenance, river and harbour improvements and fen drainage throughout the 17th century, but this was on a small scale (with the exception of Bedford Level drainage) and reliant on local tradespeople, managed by local gentry with some input from surveyors. It was not sufficient for contractors to make a transition from master craftsmen to builder/general contractor. Westminster Bridge (1738–1750) was by far the largest civil engineering project of the first half of the 18th century (Figure 2.1.3). There were 14 successive contracts for dredging the foundations placed with the Lambeth bailsman Robert Smith; contracts for the carpentry were placed with James King, a Westminster carpenter and John Barnard, later succeeded by King's assistant William Etheridge.

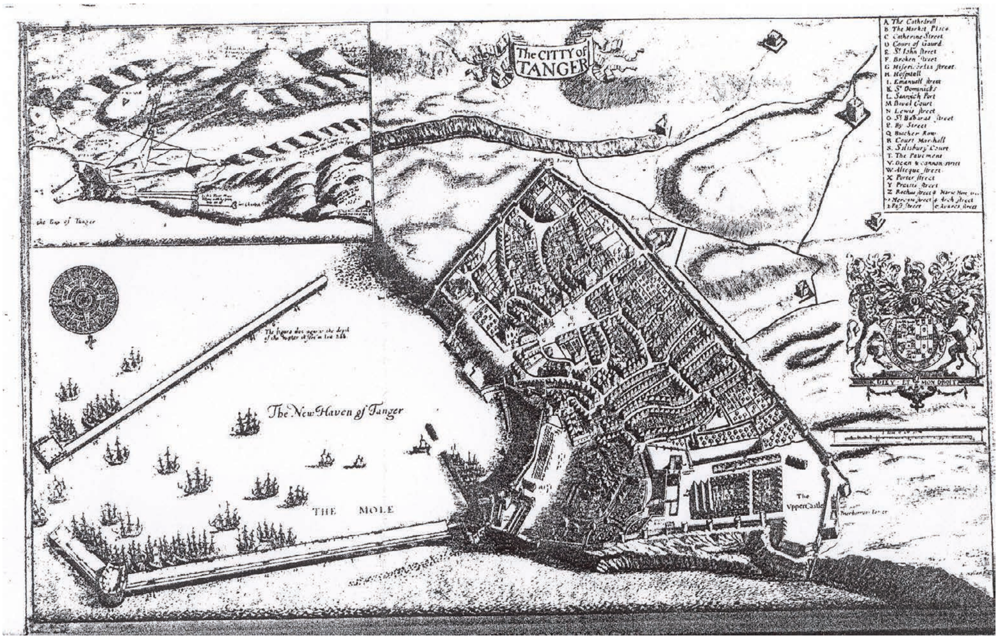


Figure 2.1.2 Tangiers harbour and breakwaters ca. 1680.

Source: Routh (1912).

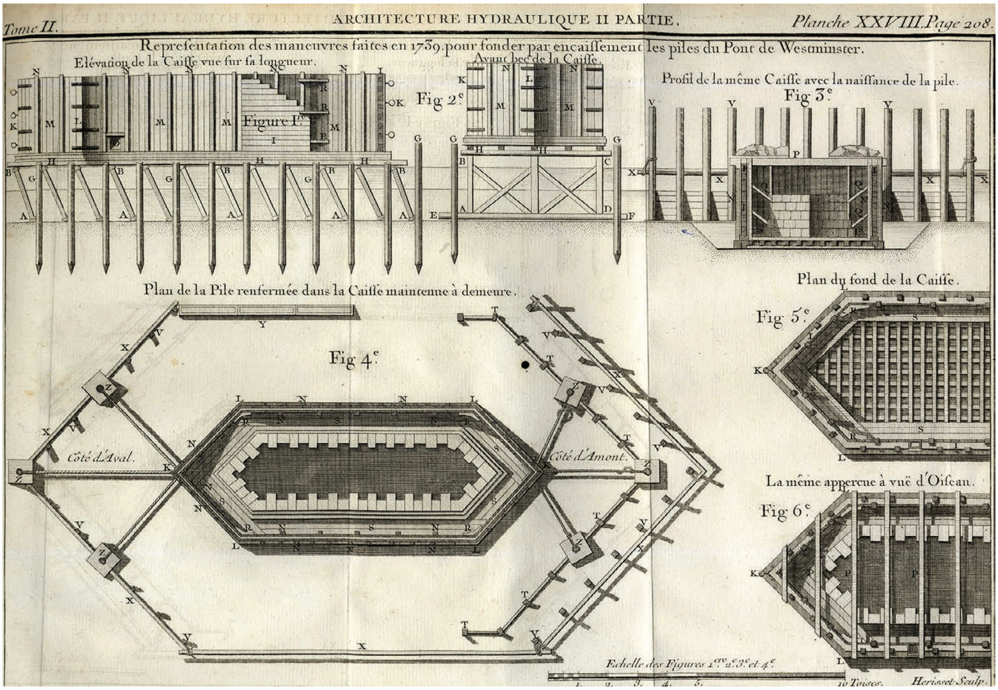


Figure 2.1.3 Caissons for the piers of Westminster Bridge (Belidor 1753: Plate XXVIII).
Source: Institution of Civil Engineers (ICE) Archives.

The first masonry contracts, for the middle two piers, were given to the local mason Andrews Jelfe and Samuel Tufnell who probably provided the capital. Jelfe had building and also civil engineering experience at Rye harbour; further contracts followed for the abutments and intervening piers, with King being awarded additional contracts for the centring of successive piers. In all, there were at least 89 contracts of various kinds, on a by-trade basis, reflecting the challenge of the engineering and the lack of capital resources for such works at that time (Walker 1979: 285–289).

Elsewhere, there were examples of engineers/master craftsmen offering design-and-build services, such as John Perry at Dagenham Breach (1716–1723), a project which Perry was able to complete because of sound financial backers and that of his former foreman John Reynolds at Rother level, Newhaven, Littlehampton; the Dee navigation, Bridport; and Southwold harbours.

The Canal Age

After 1750, the number and scale of public works contracts increased steadily – indeed, dramatically in the heady days of canal mania (Skempton et al. 2002: xii–xxxiv, 831–836; Chrimes 2004). This made it possible for master craftsmen to find steady work and upsize their businesses, and organizers of gangs of diggers or navvies could also develop their operations. In that regard, experience came from drainage works and also the massive feats of muck shifting required by the fashion for landscape gardens.

With their associated waterworks and hothouses, these landscape gardens can reasonably be described as major civil engineering works, although generally overlooked by civil engineering historians. Capability Brown has received some recognition as a dam designer (Binnie 1987; Skempton et al. 2002; Clarke et al. 2017), but the scale of his enterprise as a design-and-build contractor has been largely overlooked (Floud 2020). It has been estimated that his annual income in modern equivalence was in the order of £21 m, peaking on occasion at around £60 m, on the back of work worth something like £1 bn (Floud 2021: 117–129). This is unsurprising, given that he was undertaking the equivalent of several Westminster bridges and dwarfed the income of well-known civil engineers like John Grundy and John Smeaton in other navigations works (Figure 2.1.4). The organizational and technical skills leant themselves to transfer to the near contemporary canal schemes of the second half of the 18th century, and indeed this is seen in the canal contractors whose careers we can describe.

The Canal Age began with James Brindley's work on the Bridgewater Canal in 1759 and overlapped with the railway age as Thomas Telford completed his great canal improvements in the 1820s when work began on the Liverpool and Manchester Railway. These works were generally more numerous and on a larger scale and of higher capital value than civil engineering works of previous generations (Table 2.1.1).

In the third quarter of the 18th century, contracts were still let on a trade-by-trade basis, with small lots being common, little if anything by way of a written specification, and active supervision by proprietors/directors as well as resident engineers and overlookers. Smeaton provided a now familiar model for the management of canal construction using resident engineer, assistant engineers and overseers for the Forth Clyde Canal in 1768 (Smeaton 1812: 2, 122). By then, Brindley and his associates had been engineering canals for nearly a decade.

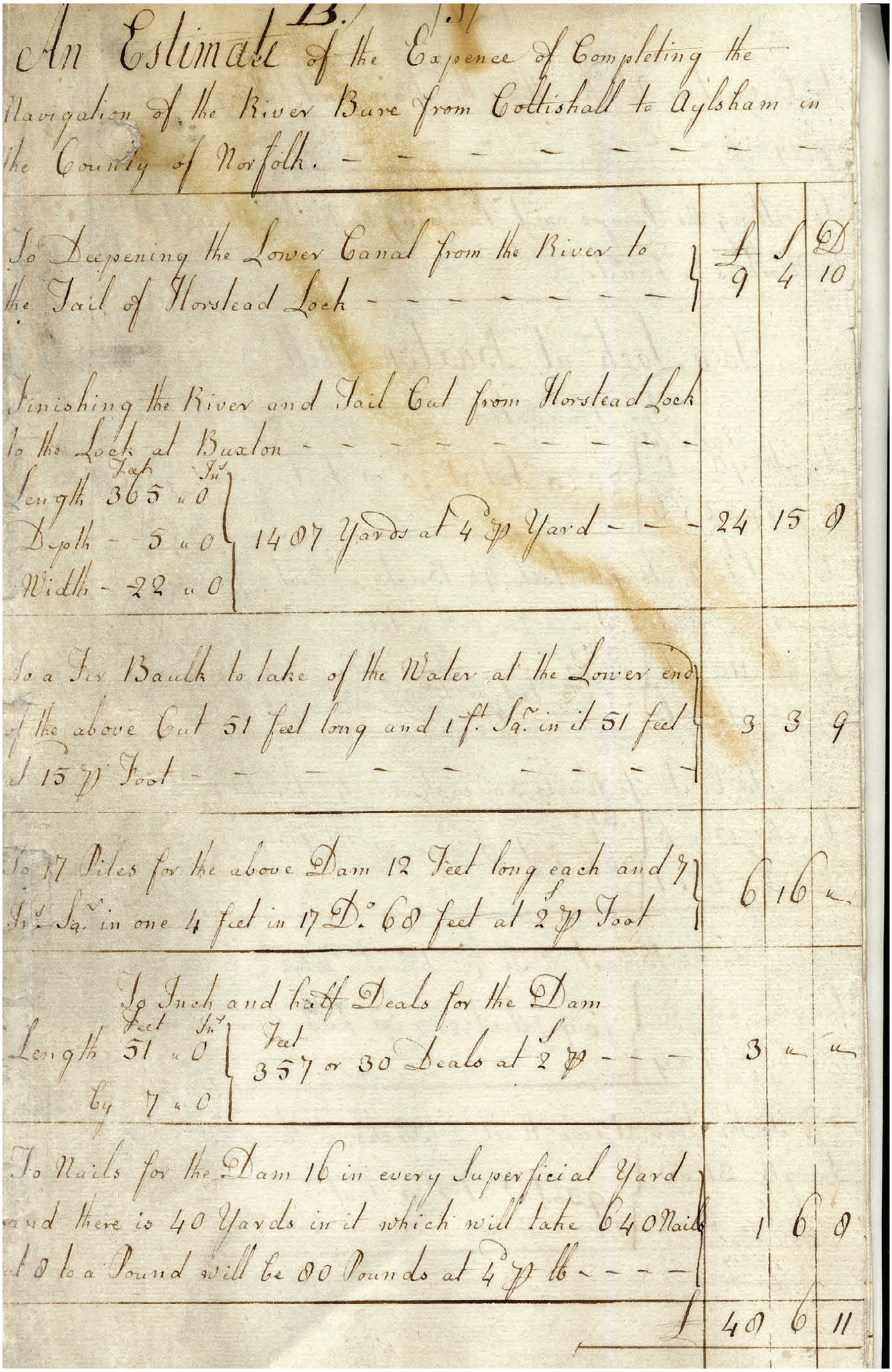
One can identify the names of canal contractors from the records of canal companies. These are rarely complete, and it requires persistence to identify their careers before 1800. Some – perhaps the more ambitious – moved from contracting to "engineering" or in the other direction, sometimes several times, as well as pursuing other business interests. While many were local, some moved great distances – for example, moving under the engineer Robert Whitworth from the Forth Clyde Canal to the Leeds and Liverpool Canal. Alexander Stevens, famous as the contractor for John Rennie's Lune Aqueduct on the Lancaster Canal (Figure 2.1.5), was already well established as a design-and-build contractor for bridges in Scotland.

Where a skilled local workforce was lacking, advertisements were placed in local papers and elsewhere (Figure 2.1.6) – perhaps most commonly for miners required for tunnelling work, but also where it was known that proprietors were carrying out other types of work.

The *Biographical Dictionary of Civil Engineers* (Skempton et al. 2002) contained memoirs of 30 canal contractors, a tenfold increase on previous published biographies. Fifteen more were excluded because insufficient information was available; beyond them, subsequent research has identified over 200 names appearing perhaps once in surviving archives (Cross-Rudkin 2010). Previous experience varied – William Dickson had worked on gardens and as an agent for John Pinkerton on land drainage and other schemes before commencing canal contracting. John Beswick worked on an estate of the Earl of Warrington and Stamford before being employed on the Staffordshire and Worcestershire Canal on which the Earl was a shareholder. William Mitton came to canal contracting from work on turnpike roads.

The Pinkerton family, arguably the first to be worthy of consideration as national public works contractors, began as land drainage contractors in Lincolnshire and the East Riding of Yorkshire. Although not unique in running a number of jobs at some distance from each other, they were probably the first to do so over a lengthy period of time.

The first Pinkerton to come to notice was James Pinkerton, at work on the Adlingfleet Drainage in 1767, but it was his younger brother John (d. 1813) who gained national prominence if



B.

An Estimate of the Expence of Completing the Navigation of the River Bure from Coltishall to Aylsham in the County of Norfolk.

	£	S	D
To Deepening the Lower Canal from the River to the Tail of Horstead Lock	9	4	10
Finishing the River and Tail Cut from Horstead Lock to the Lock at Buxton Length 365 .. 0 Feet In. Depth 5 .. 0 Width 22 .. 0 1407 Yards at 4d p Yard	24	15	8
To a Fir Baulk to take of the Water at the Lower end of the above Cut 51 feet long and 1 ft. Sq. in it 51 feet at 15d p Foot	3	3	9
To 17 Piles for the above Dam 12 Feet long each and 7 In. Sq. in one 4 feet in 17 Do. 68 feet at 2s p Foot	6	16	..
To Inch and half Deals for the Dam Length 51 .. 0 Feet In. by 7 .. 0 357 Feet or 30 Deals at 2s p	3	..	..
To Nails for the Dam 16 in every Superficial Yard and there is 40 Yards in it which will take 640 Nails at 8 to a Pound will be 80 Pounds at 4d p lb	1	6	8
£	48	6	11

Figure 2.1.4 Estimate for work on the Bure Navigation by the contractor John Smith, 1779. Even allowing for changes in monetary value, the small sums involved were typical of mid-18th century contract work – totalling perhaps £6,000 for the whole navigation.

Source: ICE Archives.

Table 2.1.1 Indicative Cost of Civil Engineering Projects, 1750–2022

Work	*Date*	*Contemporary Value*	*Measuring Work Project Value*
Westminster Bridge	1750	£198,000	£4.6 bn
Leeds and Liverpool Canal	1816	£730,000	£4.9 bn
Liverpool and Manchester Railway	1830	£600,000	£3.1 bn
London and Birmingham Railway	1839	£5 M	£25.7 bn
Metropolitan District Railway	1865	£1.7 M	£4.12 bn
Elizabeth Line	2022	£25 bn	

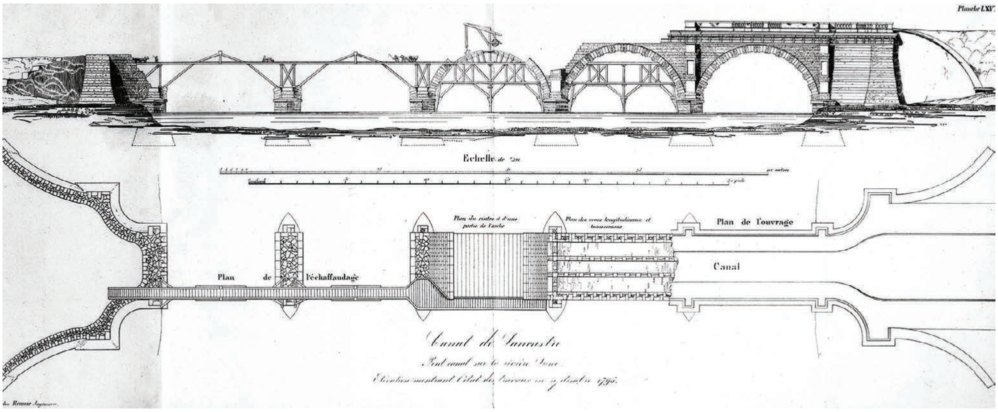
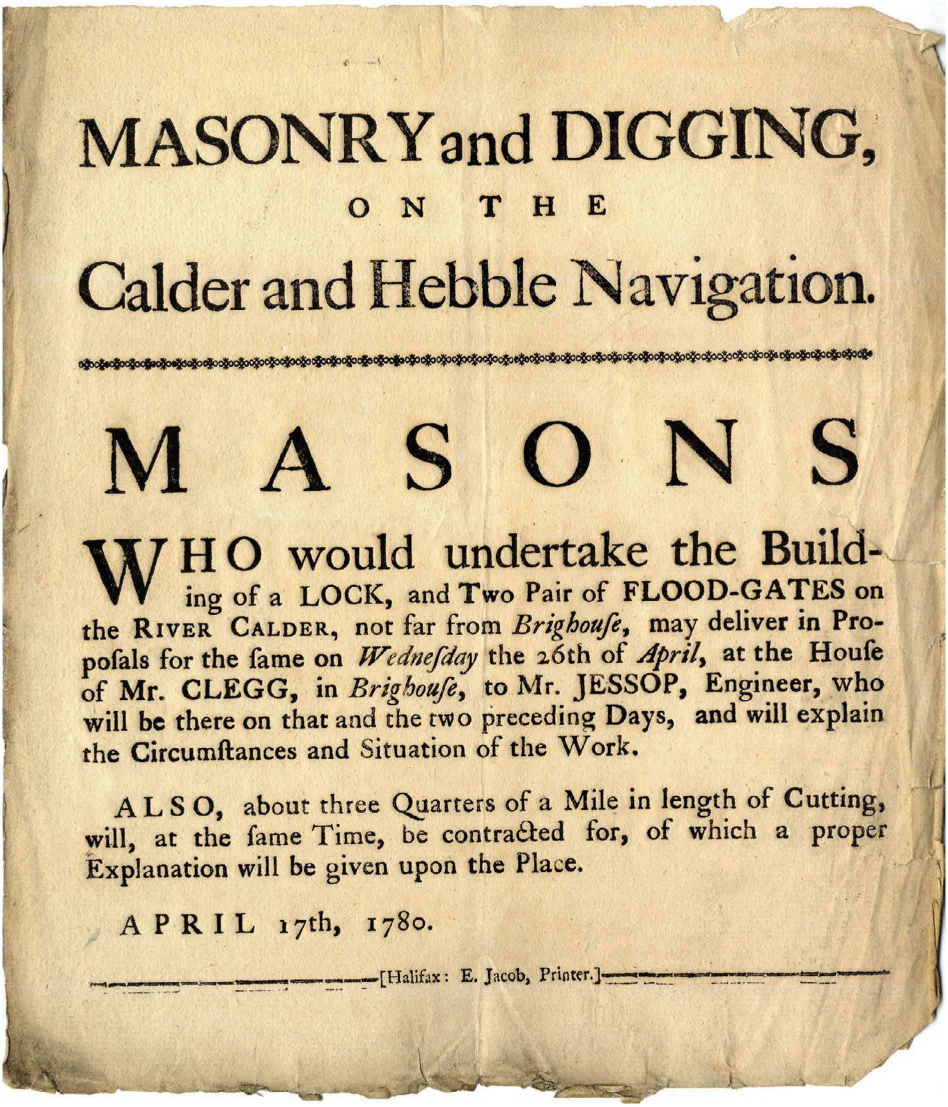


Figure 2.1.5 The Lune Aqueduct under construction in September 1795, by Alexander Stevens & Sons (Brees 1838).

Source: ICE Archives.

not notoriety through his work on a number of canals across England. He gained the confidence of the leading engineer of the 1780s and 1790s, William Jessop, with whom he shared in a number of business enterprises, and was elected to the (Smeatonian) Society of Civil Engineers, whose membership was normally confined to consultants and gentlemen. James Pinkerton was the sole contractor on the Basingstoke Canal (1788–1794) at a time when this was otherwise unknown. He was not always successful; he forfeited half of his retention money on the Dudley Canal where the difficult ground made his pricing of the tunnel a loss maker, and on his half of the Birmingham and Fazeley Canal, he fell out with the resident engineer and got into a court case with the canal company over claims. Although resolved in his favour, he was subsequently fined for libelling the company clerk. Pinkerton was also involved in litigation over overpayment and claims on the Barnsley Canal resulting in him having to compensate the company, although Jessop, the engineer and arbitrator had looked on his claims favourably, commenting on his excellent record keeping. Members of the Pinkerton family continued contracting into the 19th century, but without making a notable impact.



MASONRY and DIGGING,

ON THE

Calder and Hebble Navigation.

MASONS

WHO would undertake the Building of a LOCK, and Two Pair of FLOOD-GATES on the RIVER CALDER, not far from *Brighouſe*, may deliver in Propoſals for the ſame on *Wedneſday* the 26th of *April*, at the Houſe of Mr. CLEGG, in *Brighouſe*, to Mr. JESSOP, Engineer, who will be there on that and the two preceding Days, and will explain the Circumſtances and Situation of the Work.

ALSO, about three Quarters of a Mile in length of Cutting, will, at the ſame Time, be contracted for, of which a proper Explanation will be given upon the Place.

APRIL 17th, 1780.

[Halifax: E. Jacob, Printer.]

Figure 2.1.6 Notice inviting tenders for work on the Calder and Hebble Navigation 1780.

Source: ICE Archives.

Jessop was not alone in cultivating a relationship with contractors he regarded as reliable; Telford as well is well known for long-term relationships with the mason John Simpson, his partner William Wilson and members of the Hughes family. They variously accompanied him on his surveys of works in the UK and Sweden, advising him no doubt on prices as well as taking on work when offered (Day 1997; Pattinson 2007). Such apparent collusion with contractors can be likened to the "early contractor engagement" now seen as a key to successful delivery of major projects. Telford clearly articulated the benefits of working with known contractors, rather than accepting the lowest tenders, as seen in the *Treatise on Roads* by his client, Sir Henry Parnell, which Telford spent many days revising in 1833:

> The True principle to go upon in selecting a contractor is to lean in favour of liberal terms; and rather to overpay than underpay him. He should be made quite confident by his bargain, that he will then embark upon his work with spirit, and be led by a desire to gain reputation to perform his agreement to the satisfaction of all parties; but when, in following an opposite principle, a contractor is led by competition to undertake a work for a price that is too low, he starts, from the commencement, by having recourse to every species of contrivance for avoiding the fair fulfilment of what he is required to perform; everything is done in an imperfect way [. . .] if a contractor of established reputation for skill, and integrity, and possessing sufficient capital, is willing to undertake the work for the estimated sum, it will always be decidedly better to make an agreement with him than to advertise for tenders.
>
> (Parnell 1833 228–229)

John Rennie was another leading engineer who tried to persuade his clients of the wisdom of such an approach, noting: "I hold it as a principle that every contract should be mutually beneficial to the parties" (Cross-Rudkin 2022: 49–54). This attitude seems to have been lost on some of the early main line railways, where engineers like Robert Stephenson and I.K. Brunel were very much the sole arbitrator, and in Brunel's case, certainly in the early years, he consistently held the line in the client's favour when there were claims. Rennie's documentation was generally exemplary (Figure 2.1.7), and he was perhaps the first engineer to produce printed specifications; contract documentation was very loose on the early canals.

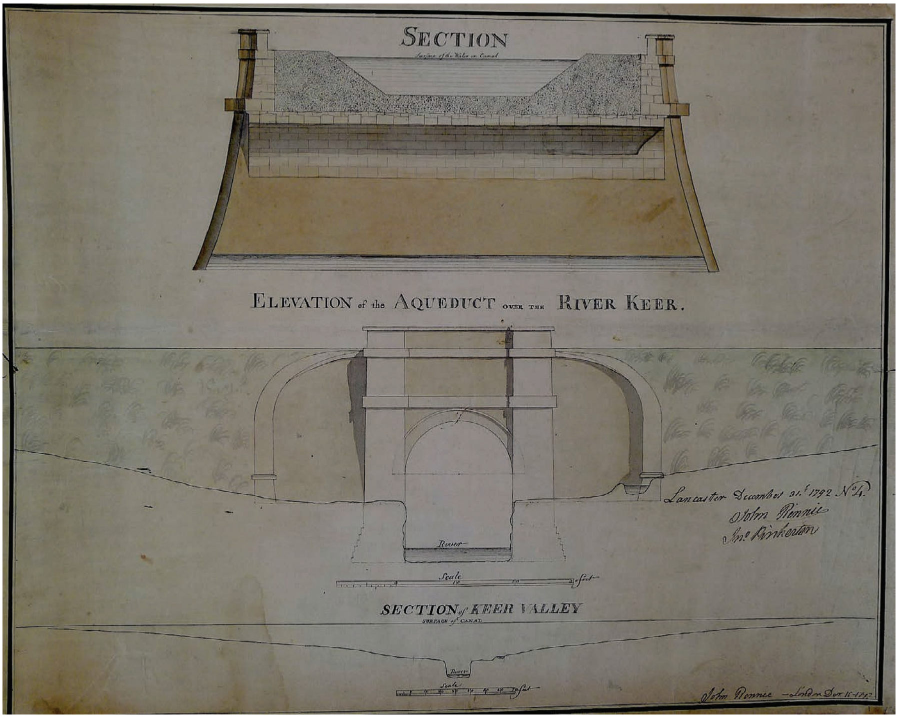


Figure 2.1.7 Contract drawing for Keer Valley Aqueduct on the Lancaster Canal, signed by John Pinkerton and John Rennie.

Source: ICE Archives.

There is uncertainty over the numbers employed by the early canal contractors: small teams must have been common. The Leeds and Liverpool Canal was unusual in recording the size of the total workforce in the 1790s, showing considerable difference between seasons – 577 in November 1798 and 277 a year later. In 1795, there were 700 people working on one section of the Montgomeryshire Canal, a surprising number given its rural location. One of Brindley's early canals, the Staffordshire and Worcestershire, had 400 on site, with John Beswick, the largest contractor employing 80–100 (Cross-Rudkin 2005). Thomas Jackson and his partner John Robinson may have been employing 400 men on their contract on the Oxford Canal in 1770. While earthwork gangers must all have struggled to retain workers in harvest seasons, in some parts of the UK of low population, notably in the highlands of Scotland, obtaining a workforce must have been a challenge, as was familiarity with equipment. Indeed, it was common for clients to provide some elements of plant to ensure work was done quickly and well.

The First National Contractors

In the 1790s, two new enterprises emerged who within a decade were operating on a scale hitherto unfamiliar and which anticipated the great era of railway contractors: Jolliffe and Banks and Hugh McIntosh. Both Hugh McIntosh (1768–1840) and (Sir) Edward Banks (1770–1835) (Figure 2.1.8) apparently came from poor backgrounds and started out as labourers; one assumes they were rapidly recognized as effective gangers on canals. In Banks' case, his partners Colonel

Figure 2.1.8 Sir Edward Banks.

Source: ICE Archives.

Hylton and Revd William Jolliffe could provide the capital necessary to upscale and take on more contracts, but it is unclear how McIntosh achieved that. Despite their humble origins, it is evident both were literate and numerate and were well organized and proved able to make good profits over many years.

Banks had begun contracting on sea defence works in Yorkshire and then worked on the Leeds and Liverpool, Lancaster and Huddersfield canals. He met the Jolliffe as a result of work under Jessop on the Surrey Iron Railway, in which the Jolliffe had an interest as they owned a quarry at Merstham. They formed a partnership in 1803, partly as building materials suppliers, which persisted until 1833. Banks was already well known to most of the leading engineers and took on the major bridges over the Thames – Waterloo, Southwark and London – designed by the Rennie as well as Sheerness dockyard and other major works. McIntosh's breakthrough may have been the excavation work for East India Docks: by 1817, he was offering to take on the whole of the Edinburgh & Glasgow Union Canal, although in the event, he only took about half the work. Both were recognized as significant men of property in their lifetimes, Banks was knighted and was the subject of at least three portraits, while McIntosh was referred to as "worth £1,000,000 of money" (Chrimes 1997: 201). He was able to afford to send his son David to Glasgow University and commission his portrait (Figure 2.1.9).

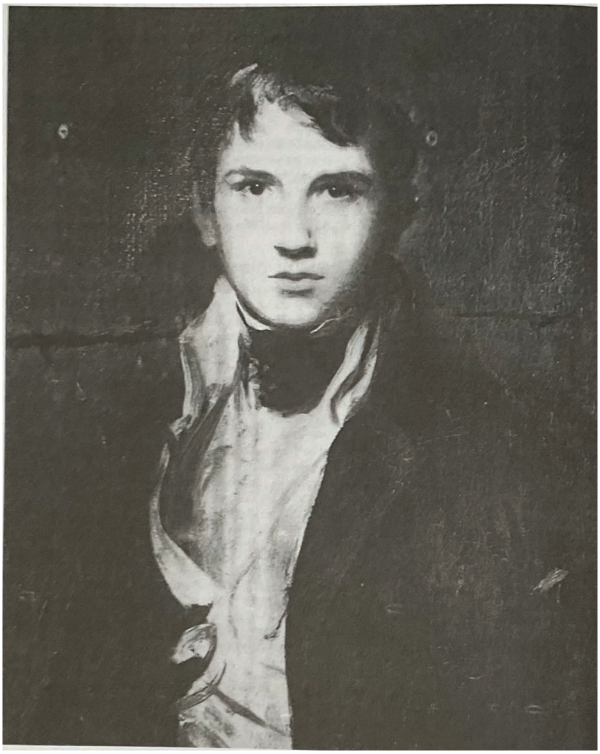


Figure 2.1.9 Portrait of David McIntosh by Sir Thomas Lawrence, 1813 (the original was lost).

Source: ICE Archives.

The scale of their enterprises compared with what had gone before is evident from reference to Tables 2.1.2 and 2.1.3. Their accumulated wealth was rarely surpassed by future generations. It has been suggested that Jolliffe and Banks had more diverse business interests, including steamers, but McIntosh developed a property portfolio and seems to have undertaken a broader range of work, notably relatively small contracts for gas and water companies. McIntosh was possibly also the first contractor to undertake an overseas contract, for the government at Flushing (Vlissingen) in 1809. Of course, some work overseas was done by British consultants and manufacturers in the early 19th century, but it was the advent of the railways that created the demand and finance for contractors to take work abroad on a large scale. Before then, it was down to individual artisans, for example working on the Gotha Canal, or moving to overseas colonies to seek their fortune.

Table 2.1.2 Leading Contractors' Major Works, 1750–1914 (Chrimes 2019a; Cross-Rudkin et al. 2008; Skempton et al. 2002 and Table 2.1.7)

Name	*Dates Active*	*Number of Contracts*	*Number of Railway Contracts*	*Contemporary Value*
Thomas Brassey	1834–1871	c. 190	174	£65–£100 m
Brassey and Ogilivie		45	42	£10 m
Sir R. McAlpine and Sons	1868–(1914)	125	53	£7.3 m
S Peto.	1830–1872	123	98	£38 m
H & D McIntosh	1790–1841	119	35	£6.5 m
George Pauling, etc.	1881–(1914)	119	109	£32 m (1930)
S. Pearson and Sons	1854–1926	115	26	£63 m
Joliffe and Banks	1789–1834	102	1	£4 m
J. Aird and Sons (incl. Aird and Lucas)	1848–1912	83*	31	
W. Scott and Middleton	1849–1910	66*	38	£5 m+
(Sir) J. Jackson	1875–(1914)	64	5	£35 m
Fox Henderson	1841–1856	63	5	
Woodiwiss and Benton	1840–1880	62	56	
Nowells (incl. Hattersley Monk)	1780–1890	61	49	
William Mackenzie	1834–1851	61 (incl. M&B)	54	£18 m
W. Dargan	1819–1856	58	37	£10 m
G. Wythes	c. 1837–1875	57*	51	£20 m
Warings	c. 1835–1880	48*	43	£15 m
Tredwells	1805–1870	45*		
Jackson and Bean	1821–1880	41	20	
J. & J. T. Firbank	c. 1841–1900	38	38	
Lovatt	1851–1913	50*	34	
Davies and Savin	1855–66	20	20	c. £5 m
Canal Contractors for comparison				
John & George Beswick	1759–1795	17		
Houghton & Ford	1760–(1831)	8*		
Pinkerton	1755–1830	49		£750 000

* Underestimate

Table 2.1.3 Leading Contractors' Estates, 1800–1914

Name	*Date of Death*	*Estate*	*Ranking by Works (Table 2.1.2)*
Thomas Brassey	1871	£3,200,000	1
George Wythes	1882	£1,524,787	15
Sir Walter Scott	1910	£1,424,130	9
Sir John Aird	1911	£1.1 m	8
Edward Mackenzie	1880	£1 m	14
Alexander Ogilvie	1886	£747,801	16
George Benton	1887	£606,593	12
Thomas A. Walker	1886	£597,394	15
Charles Waring	1887	£560,429	20
Sir John Jackson	1919	£520,474	10
David Davies	1890	£404,424	20
William Mackenzie	1851	£383,500	14
Joseph Firbank	1886	£348,528	20
Benjamin Piercy	1888	£324,574	*
Charles Thomas Lucas	1896	£312,078	8
Alfred William Bean	1890	£301,979	15
Hugh McIntosh	1840	£300,000	4
William Barningham	1885	£295,505	*
John Towlerton Leather	1885	£256,983	*
Edward Banks	1835	£250,000	7
Thomas Tredwell	1862	£250,000	17
Sir Abraham Knight Woodiwiss	1884	£233,508	12
William Cubitt	1863	£200,000	*
William Galloway	1873	£200,000	*
Thomas Grissell	1874	£200,000	3
John Tredwell	1876	£200,000	17
Joseph D'Aguilahn Samuda	1885	£199,350	*
John Aird snr.	1876	£140,000	8
David McIntosh	1856	£140,000	4
Thomas Docwra	1883	£120,327	*
John Waddell	1888	£148,789	*
Sir William Fairbairn	1874	£120,000	*
John Pinkerton	1813	£7,500	
Samuel Weston	1805	*c.* £5,000	

* Other business interests or under 20 major works

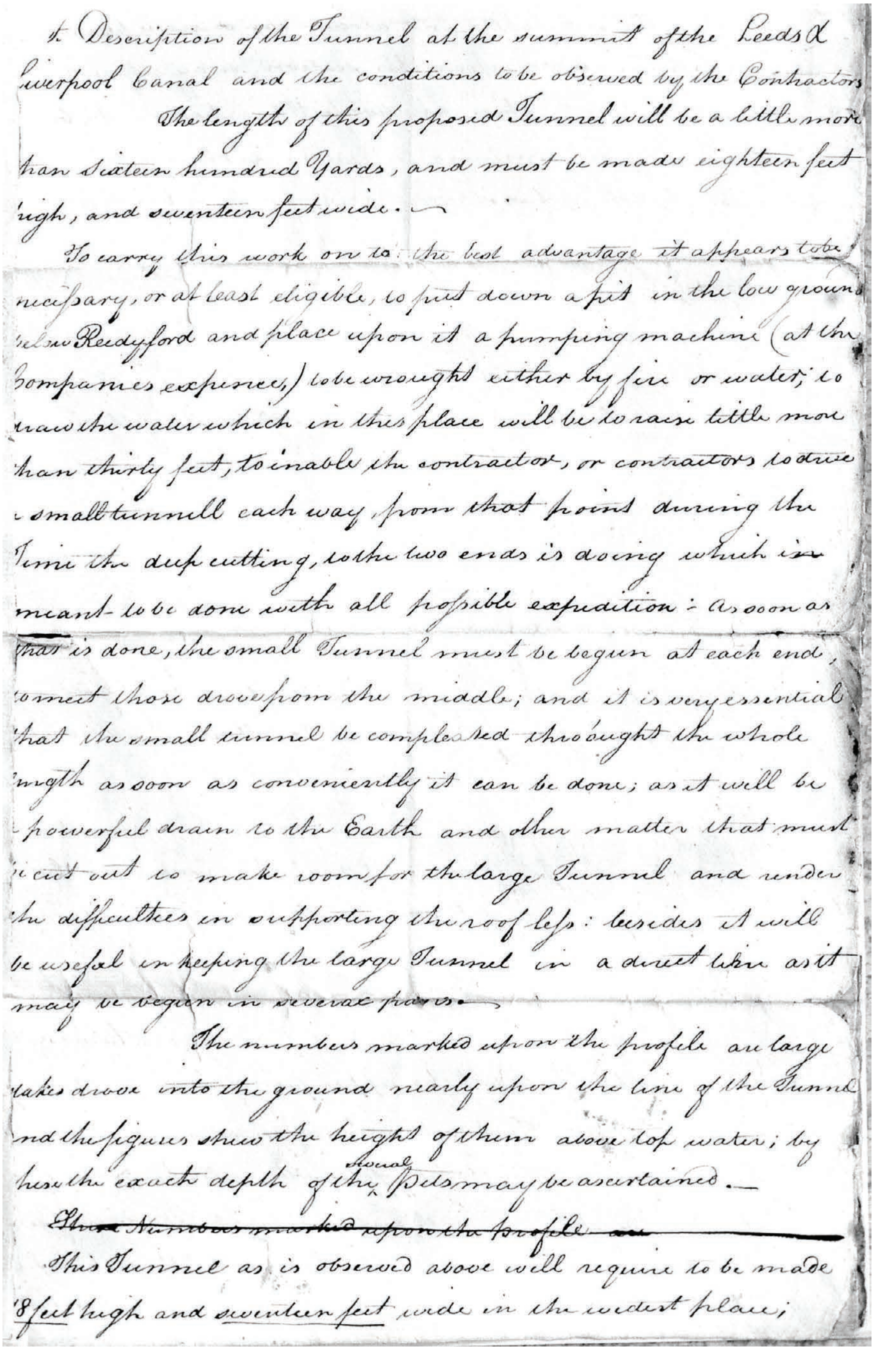
It was the organizational methods established by Banks and McIntosh that set the framework for the drive overseas. They went beyond the employment of foremen and site representatives. The role of site agent, a contractors' representative able to make financial decisions on behalf of the main contractor and the use of subcontractors were essential. Whether such agents took a share in profits, that is whether they were effectively partners, is unclear. However, in McIntosh's case, profits share seems likely as a means of sharing the capital risk. The wealth of both firms means they could have employed lawyers, accountants and surveyors. McIntosh had an office in central London, in Bloomsbury Square, and both employed permanent office staff. The names of a number of McIntosh's agents are known – his brother James, his son David, who later took contracts in his own name, James Leishman, the Radfords, Hugh and Alexander Mackenzie Ross, William Henderson, Alexander Mackenzie and William Betts. For Banks (1795–1861), his nephew John Plews ran the office for the 12 years until Banks' death and later became a dock contractor. One of his partners, on the London Bridge job, at least, was the well-connected Henry Outram Henfrey, (d. 1827) a nephew of the engineer Benjamin Outram and cousin of General Sir James Outram (1803–1861), who had a successful career in India. His brother-in-law James Hollinsworth (d. 1828) was one of John Rennie's assistants and Sir John Rennie's resident engineer on London Bridge.

One reason these two firms are not better known is that their names have been overshadowed by those of the railway contractors who followed; however, they were at least as financially successful. In reality, there was something of a natural transition between the canal and railways era, and the notion of a hard break is partly the result of generational change: McIntosh and Banks were coming to the end of their working lives by the 1830s when the first railway mania took place, and many of the early canal contractors had passed on some time earlier. However, many of the early contractors – for instance on the London and Birmingham Railway, under construction in the mid-1830s – had worked on the canals and other projects of the 1820s or their parents had (Table 2.1.4) . Moreover, Hugh and David McIntosh did take on a number of railway contracts, successfully, and were involved in a notorious law case with the Great Western Railway, found in their favour after both their deaths! Among their agents and assistants, William Betts and his son Edward Ladd Betts both became railway contractors, as did Alexander Mackenzie's son William. The children of Robert Aird, who died in an accident on one of McIntosh's jobs, found their way into contracting on McIntosh's gas contracts, and becoming one of the major contracting forces of the late 19th and early 20th centuries. Charles Henfrey became an important agent of Thomas Brassey, and there must have been dozens of masons, carpenters and gangers who were taken for railway work who had worked for Banks and McIntosh.

The Specialist Contractor

While the early 19th century saw the rise of the large general public works contractor, new specialisms were becoming established alongside those of the mason and carpenter. The recruitment of miners for tunnelling work took place alongside that of carpenters and masons on the early canals, but the difficulty and financial risk of such work may have deterred specialists, and some undoubtedly took fright as their contracts became a liability, the name of Charles Jones being an obvious example. On longer tunnels, it was common for a number of teams to be at work. On the Foulridge Tunnel, on the Leeds and Liverpool Canal, at least six teams were at work in 1791–1792: local firms led by Christopher Smithson; John Tickle in partnership with John Wood; James Porteous and James McIlquham from Dumbartonshire; John Murray also from Scotland; James Paulson and Thomas Leyburn from Barnard Castle and Sunderland respectively; and Thomas Barber Jones and Joseph Glazebrook from Broseley (Anonymous 1791–1792) (Figure 2.1.10).

Even the Pinkertons found such work difficult. But around 1800, the partnership of Pritchard and Hoof emerged. Daniel Pritchard (c. 1777–1843) almost certainly had an experience of colliery work in the Wrexham area, and Hoof, his son-in-law, had a similar background in the Shropshire coalfield. They undertook, successfully, seven tunnel contracts in the early 19th century including some of the largest (Strood) and the longest ones (Harecastle), developing specialist centring and earning the praise of the engineers involved – W.T. Clark and Telford. They also worked on some



A Description of the Tunnel at the summit of the Leeds & Liverpool Canal and the conditions to be observed by the Contractors

The length of this proposed Tunnel will be a little more than Sixteen hundred Yards, and must be made eighteen feet high, and seventeen feet wide. —

To carry this work on to the best advantage it appears to be necessary, or at least eligible, to put down a pit in the low ground below Reedyford and place upon it a pumping machine (at the Companies expence) to be wrought either by fire or water; to draw the water which in this place will be to raise little more than thirty feet, to inable the contractor, or contractors to drive a small tunnell each way from that point during the time the deep cutting, to the two ends is doing which is meant to be done with all possible expedition: As soon as that is done, the small Tunnel must be begun at each end, to meet those drove from the middle; and it is very essential that the small tunnel be compleated throught the whole length as soon as conveniently it can be done; as it will be a powerful drain to the Earth and other matter that must be cut out to make room for the large Tunnel and render the difficulties in supporting the roof less: besides it will be useful in keeping the large Tunnel in a direct line as it may be begun in several parts. —

The numbers marked upon the profile are large stakes drove into the ground nearly upon the line of the Tunnel and the figures shew the height of them above top water; by these the exact depth of the Actual Pits may be ascertained. —

~~These Numbers marked upon the profile are~~

This Tunnel as is observed above will require to be made 18 feet high and seventeen feet wide in the widest place;

Figure 2.1.10 Conditions to be observed by contractors on the Leeds and Liverpool Canal, c. 1791.

Source: Mike Clarke.

early main line railway contracts including Berkswell on the London and Birmingham Railway, which was one of the first where a contractor used a locomotive to move spoil. Hoof continued in business until c. 1851, while one of Pritchard's sons made his career in Australia.

The introduction of structural ironwork provided another field in which specialist contractors developed. The iconic Iron Bridge manufactured by the Coalbrookdale Company attracted much attention from its opening in 1779. Its construction relied heavily on the expertise of the iron founders, and a characteristic of the early iron bridges was a close collaboration between the iron masters and the designers, particularly important for longer spans and the casting of large elements. Well-known examples are Telford's collaboration with William Reynolds and William Hazledine, and later the Horseley works, and Thomas Wilson and Rennie's collaboration with Walkers of Rotherham. Jessop and Benjamin Outram had a financial interest in the Butterley Company, and Outram provided a design-and-build service for the supply of early railroads to canal companies and other clients, with Butterley pricing their rails, and the sub grade managed by Outram.

In most early cases, clients and engineers would have worked with iron masters they trusted, rather than putting designs out to general tender. Around 130 cast iron bridges have been identified before 1830 (Cossons & Trinder 2002), including a number of "off-the-shelf" designs, presumably dimensioned by the ironworks staff, and based on full-scale testing. Watkin George of Cyfartha Ironworks worked on a design-and-build basis, and John U. Rastrick and William Cubitt designed bridges on behalf of their foundries (Bridgnorth & Stourbridge and Ransome's, respectively). William Tierney Clark may have done design work at Coalbrookdale before moving to Rennie's Albion works.

Rastrick designed large beams (36 ft/11 m span) for the British Museum Library, and it is likely that it is in the supply of structural ironwork for buildings that ironwork suppliers first took on the role of design and dimensioning as part of the tendering process. In the case of a major stockist like Richard Moser of Southwark, agent for Crawshays and suppliers of ironwork for Buckingham Palace in the 1820s, it is unclear what design role they played, but the contemporary London ironworks of Cottam & Hallen employed William Turnbull to get dimension beams for their clients, based on the theories of Thomas Tredgold (Thorne 1990). The London firms of Henry Grissell and Bramah & Sons also established a reputation for the supply of structural ironwork in the 1820s and continued into the railway age, members of the Bramah family being involved with the firm of Fox, Henderson which was the perhaps best known of the mid-19th century iron work contractors, employing gifted designers such as E.A. Cowper and R.M. Ordish, as well as Charles Fox himself. Early structural iron framing for textile mills had been the result of design work by mill owners like Charles Bage and William Strutt, who were gifted engineers. Ironwork for the Ditherington Mill designed by Bage was supplied by Hazledine, himself a millwright by training. However, as demand grew, specialist suppliers rapidly emerged, the most famous being that of William Fairbairn, who was able to equip whole mills from the 1820s, branching later into bridge supply and shipbuilding, all with a growing export trade (Figure 2.1.11). Again, he made use of great scientific minds like Eaton Hodgkinson and William C. Unwin (Byrom 2017).

Fairbairn's career took him into the world of wrought iron, and, from the 1850s, there were a number of firms supplying such bridges for the railway market (Figure 2.1.12), with their own engineers Ewing Matheson at Handysides, Henry Maynard at Kennards and Hutchinson at Skerne producing catalogues of their designs. Another area of specialism which gained momentum from the early 19th century was equipping gas works, with the Cutler family specializing in gas holder supply from the 1840s.

Figure 2.1.11 Saltaire Mill near Bradford, one of Fairbairn's outstanding works.

Source: The author.

Figure 2.1.12 A typical British railway export: Joannes viaduct on the Bahia and San Francisco Railway under construction by John Watson in 1861; Watson's inability to convert bonds he held on the Mid Wales Railway in the spring of 1866 precipitated the Overend–Gurney crisis of 1866, although he eventually discharged his bankruptcy.

Source: Benjamin Mullock photographs, Vignoles collection, ICE Archives.

The Railway Age

It is surprising that George Stephenson and the Directors of the Liverpool and Manchester Railway did not let out the work on the line to contractors by competitive tender as the system was well established by the 1820s. This may have been because Stephenson and his backers were anxious to control all aspects of railways or the recent experience of jobbery in Liverpool Docks. It was however a decision that was widely criticized and seen as pushing up costs. At any rate, the main line railways of the 1830s were generally let by competitive tender. The London and Birmingham Railway was let in smallish lots – to suit what was believed to be the means of the likely contractors. Most had relevant experience (Figure 2.1.13; Table 2.1.4). Although Banks and McIntosh were not involved, McIntosh soon began winning work – on the Great Western, Midland Counties, North Midland and elsewhere. In one instance – the London and Greenwich – the engineer, Colonel Landmann, prepared the contract drawings and documentation in McIntosh's offices.

Figure 2.1.13 Tring Cutting on the London and Birmingham; the contractor Thomas Townshend had 40 years' experience in construction (Bourne & Britton 1839).

Source: ICE Archives.

Table 2.1.4 Contractors' Experience on the London and Birmingham Railway

Contractor	*Contracts*	*Years' Experience*	*Previous Works*
Edward Beddington	4F	Unknown	Possibly a local farmer
John Burge	7C	10	St Katharine Docks
John R. Chapman	2F, 3F	Unknown	Also at work on North Midland Railway; Chapman was at work briefly on the Liverpool and Manchester Railway

(*Continued*)

Table 2.1.4 (Continued)

Contractor	*Contracts*	*Years' Experience*	*Previous Works*
James Copeland	3B	10	Liverpool and Manchester, Leicester and Swannington Railways
Hiram Craven	3C	30	Hull Docks, Yorkshire churches and bridges
W. & L. Cubitt	Euston extn, 4B, 5B	15	Fishmongers Hall
James Diggle	1G	5	Warrington and Newton Railway
Hugh Greenshields	4G	10	Sankey Viaduct, Liverpool and Manchester Railway
Grissell and Peto	Curzon St Station	15	Many London buildings
Thomas Harding	3B	10	Liverpool and Manchester, Leicester and Swannington Railways
Samuel Hemming	7G, 5G Avon viaduct	15	Bombay Engineers, 1819
William Hughes	1F	30	Caledonian Canal
Thomas Jackson	1B	10	Assistant to Grundy, London builder
William Mackenzie	3G,4G	25	Gloucester and Berkeley Canal, Birmingham Canal
E.W. Morris	6C	15	Holyhead Road, Birmingham and Liverpool Junction Canal
James Nowell	4C, 5C, Rea Viaduct	20	Churches
Joseph Nowell	2B, 7F	20	Macclesfield Canal, St Helens Railway
R. Parr	6B	10	Newcastle and Carlisle Railway
Daniel Pritchard	3G	30	Crick, Strood, Harecastle tunnels, etc.
W. & J. Simmon(d)s	4F, 4G, 6G	Unknown	Also at work on The Birmingham and Derby Junction Railway
William Soars	2C	20	Macclesfield Canal
George & James Thornton	5F, 6F	20	Canals, Liverpool and Manchester Railway
Joseph Thornton	2G	20	Canals, Liverpool and Manchester Railway
Thomas Townshend	1C	40	Birmingham Canal

While there was continuity with the contracting experience of the previous generation, the more vigorous, better organized, and perhaps lucky few came to the fore, such as William Mackenzie, Thomas Brassey, Samuel Morton Peto and George Wythes. The scale of these enterprises and the fortunes they made can be seen from Tables 2.1.2, 2.1.3 and 2.1.5. Their wealth generally dwarfed that of contemporary civil engineers (Table 2.1.5) and the efforts of the previous generation. By the early 1840s, many were national organizations, although some smaller

Table 2.1.5 Estates of Some Leading Civil Engineers c. 1790–1914

Robert Stephenson*	1859	*c.* £400,000
Joseph Locke*	1860	£350,000
James Walker	1862	*c.* £300,000
Sir John Wolfe Barry	1918	£278,362
Sit Thomas Bouch*	1880	£249,859
Sir John Hawkshaw	1891	£220,874
Francis William Webb*	1906	£211,543
Henry Robertson*	1888	£185,525
Sir John Fowler	1898	£179,330
Charles Sacre*	1889	£166,073
George Stephenson*	1848	£140,000
Thomas Eliot Harrison	1888	£133,748
Edward Woods	1913	£128,012
John Rennie*	1821	£122,000
J.E. Errington	1862	£120,000
Benjamin Baker	1907	£120,563
William Allcard*	1861	£120,000
Sir William Fairbairn*	1874	£120,000
Thomas Hawksley	1898	£104,698
I.K. Brunel	1859	£90,000
Thomas Telford	1834	£40,000
John Smeaton	1792	£5,000
Thomas Dadford Jnr	1801	£2,000

* Significant manufacturing or mining interest.

Table 2.1.6 English "Contractors" Probate, 1858–1894

Year Granted	*Under £1,000*	*£1,000–£10,000*	*£10,000–£50,000*	*£50,000–£100,000*	*£100,000+*	*Total*
1858–1869	237	78	28	4	2 (885)*	349
1870–1879	319	115	45	7	13 (1336)	499
1880–1889	306	91	35	5	19 (1583)	456
1890–1894	68	29	7	1	6 (927)	111
Total	930	313	115	17	40	1 415
	66%	22%	8%	1%	3%	

* Figures in brackets refer to total numbers of estates of that value taken from Rubinstein (1981: 52).

firms remained associated with their locality and particular railway companies. Of course, the railways themselves and associated advances in steam navigation made it much easier for the contractors to manage projects over a great distance (Brooke 2000; Helps 1872: 345–350).

We are of course concentrating on the larger businesses, which effectively dominated major railway and public works construction from the late 1830s. That there were many more involved is shown by reference to Table 2.1.6. Many small estates relate to house builders and sub-contractors. Given that, those individuals who are likely to be of great interest are those who accumulated reasonable wealth, perhaps over £10,000, approximately 12% of the total. Wealth as an indicator of a contractor's success would appear as an ideal measure, and it would indicate an ability to estimate accurately, tender successfully and manage works effectively to produce profitable returns on work done. But contracting has always been a high-risk business, and some important Victorian contractors were financially humbled by episodes such as the Overend–Gurney failure of 1866. This explains the absence of Sir Samuel Morton Peto, and the lesser known, but regionally very important, Thomas Savin. Peto can only have been worth a few pounds at his death – his wife's estate was only £4,000 while Savin's was declared at *c*. £100.

Through the 19th century, an estate of over £100,000 was enormous. Thus, Thomas Brassey, George Wythes and Edward Mackenzie were among the 133 wealthiest British people of the century; yet the overwhelming majority of the wealthiest ten contractors lack a full-length biography (Figure 2.1.14).

A probate index cannot tell the whole story. For contractors, estimating income is difficult. One can aggregate the value of contracts, but one has little insight into profits. Occasionally one gets a glimpse of lifestyle – for instance in the sale of Edward Betts' home in Kent following his financial ruin in the late 1860s (Figure 2.1.15). The scale of Victorian enterprise also dwarfed what had gone before, so families like the Pinkertons who were active for c. 50 years with numerous canal and land drainage contracts generated only relatively small wealth from much lower capital contracts, making direct comparison invidious.

One can perhaps add that the little-known Edward Mackenzie, retired from contracting in the 1860s, was still lending tens of thousands of pounds to firms like Smith and Knight (£80,000 was a typical figure) on often dubious security. Despite his losses, he died a millionaire on his Fawley Court estate near Henley-on-Thames. His family accountant despaired of filling in a tax form on his brother William's earnings in France. They were so great nobody would believe

Figure 2.1.14 Thomas A. Walker, agent for Thomas Brassey and others, and contractor for the Severn Railway Tunnel and Manchester Ship Canal. Despite his success, like many leading contractors, he lacks a full biography.

Source: ICE Archives.

Figure 2.1.15 Edward Ladd Betts at home, before the crash of 1866.

Source: Carte de visite, ICE Archives.

them. Edward could also afford the loss of tens of thousands of pounds embezzled by his Paris agent Favrin (Chrimes et al. 1994).

Thomas Brassey (1805–1870) and His Circle

Brassey is the outstanding public works contractor of the mid-19th century, the Mackenzie brothers forming only part of his business circle. Born into a Cheshire farming family, Brassey (Figure 2.1.16) was trained as a surveyor and involved with the early development of Birkenhead. His management of a local quarry allegedly brought him to the attention of the engineers of the Liverpool and Manchester Railway, George Stephenson and Joseph Locke, and he had the ambition and nous to decide to start tendering for railway work. He was successful with the Penkridge contract of the Grand Junction Railway and developed feeling of mutual trust with its engineer Joseph Locke on this and a number of other contracts. At the same time, William Mackenzie, who had worked as a contractor and resident engineer on a number of projects, established himself as a reliable contractor with Locke and others. As a result of his work on the London and South Western Railway, Locke was introduced to the French backers of a proposed concession from Paris to Le Havre via Rouen; Mackenzie and Brassey came together for most of the contracts on what were two French Railway companies and made a fortune out of the work (Figure 2.1.17).

Figure 2.1.16 Thomas Brassey, portrait by F. Newenham, c 1850.
Source: ICE Archives.

They were sought out by financiers and governments across Europe and able to invest speculatively in schemes in anticipation of selling shares at a premium when further concessions were granted. In the mid-1840s, they colluded on contracts for the completion of the West Coast Main Line north of Lancaster with John Stephenson, another successful contractor. These contracts were for entire lines and worth hundreds of thousands of pounds, allowing Mackenzie and Brassey to weather the financial crash of 1847–1848 and the French Revolution.

Mackenzie's health failed, but Brassey went from strength to strength through the 1850s with new but already experienced partners Samuel Morton Peto and Edward Ladd Betts and agent/partners Alexander Ogilvie and William Field. The nature of the various business relationships is unclear: they were consortia in the sense of sharing risks on individual jobs for a share in profits, but not a limited company. At times, Brassey teamed up with other giants like George Wythes. By 1860, his was a well-oiled and respected enterprise.

Brassey was responsible of over 6,500 miles of railway – something like 5% of the world's railways in his lifetime and 16% of those built in the UK (Helps 1872). His work stretched from Argentina to Canada; from Portugal to present-day Romania and from Scandinavia to Italy in

Figure 2.1.17 Photograph of part of the contract documentation and correspondence contained in the Mackenzie collection in the ICE Archives, to give an impression of the scale of the business of Mackenzie and Brassey in the 1840s.

Source: The author.

Europe and across northern India and down to Australia. He owned factories in the UK, France and Italy; was able to maintain his contracts through the Austro-Prussian war of 1866 and bale out his friends with loans and securities through the Overend Banking crisis of 1866, playing a more proactive role in keeping businesses like George Furness afloat than the Bank of England (Metropolitan Board of Works 1866: 1,124–1,125). He is alleged to have lost £1 m at this time, but still left a fortune of over £3 m and £2 m in trusts on his death in 1870, making him by far the wealthiest commoner of his generation. To put this amount in context, the Bank of England only had *c*. £5 m of assets in specie at the time of the Overend–Gurney collapse and kept going by unofficial deals with other major banks. The editor of the *Economist* at the time, Walter Bagehot, argued that the role of a central bank was to support fundamentally sound businesses through financial crises, which Brassey seems to have done for his friends – yet the Bank was seemingly unwilling or unable to do (Schneider 2022). More research is required into the way in which the construction industry kept itself afloat during this period.

A number of biographies have described Brassey's career, but no business biography exists (Helps 1872; Walker 1969). He employed over 100,000, with offices in Liverpool and London and no doubt in many foreign cities. He ran railways, built docks, sewers and waterworks and invested in property schemes such as the new town in Southend and East India Buildings in the City of London. It seems that on his death, his staff were instructed to destroy all paperwork – and it was burned in the furnaces of his Canada Works in Birkenhead (Brooke 2010a, 2010b). Fulfilling all outstanding work must have taken a decade or more, and Alexander Ogilvie maintained the London office until his death in 1886. The business of Thomas Brassey & Co was created in 1873 by his executors, Ogilvie, Wythes, J. A. Longridge, Walter Cutbill and Ulysses de Lungo, presumably largely to wind up existing contracts. Cutbill and de Lungo remained active into the 1880s, but Brassey & Co. was wound up in 1894 (Figure 2.1.18) (London Gazette 16 March 1894: 1,605).

Some former agents and associates like Thomas Walker had already developed successful contracting businesses; yet Peto and Betts were finished by the Overend–Gurney affair; Betts

Figure 2.1.18 Work on the Francis Canal in Austria-Hungary in 1874, undertaken by Brassey's Partners George Wythes and J.A. Longridge, photograph.

Source: ICE Archives.

was rescued by Brassey purchasing his home. Other experienced contractors including Lucas and Aird emerged virtually unscathed from the Overend–Gurney affair, and Aird continued into the 20th century.

Waring Brothers

While the extent of Brassey's activities is well known, that of many of his leading contemporaries is not. The Waring family are an example (see Table 2.1.7). Despite Waring Brothers being reputedly second only to Brassey in terms of global work, they remain shadowy figures. Charles Waring was a partner of Brassey on schemes such as the Metropolitan District Railway and City of Glasgow Union Railway. His father John Waring (1796–1867) was a Yorkshire mason and quarry owner and, like many of his local peers, obtained work on main line railways in the late 1830s, acting for a time with another well-known Yorkshire contractor, John Towlerton Leather.

In due course, Waring brought his sons into the business – William (1820–1894), Henry (1822–1909) (Figure 2.1.19), Charles (1827–1887) and Mark (d. 1859), ending his association with Leather by 1842. By then, the family was well-known to many leading engineers and railway companies. In the late 1840s, much of their work was for the Manchester Sheffield and Lincolnshire Railway, and they successfully weathered the crash of the late 1840s.

It is not known when they decided to venture overseas, but the temptation of higher profits must have been a great motivation. They became involved with the development of Belgium's secondary railway network in the 1850s. Henry (Figure 2.1.19) took up residence in continental Europe, and five of his children were born in Belgium and France (1857–1862). They built and operated the Manage-Wavre/Eastern Junction Railway and opened an engineering works at Nivelles to avoid tariffs. This was followed by work on the Guillaume Luxembourg line with major viaducts. They were involved in French railways, although the work on the Graissesac–Beziers Railway does not seem to have been profitable and was one of many contracts from which they managed to extricate themselves before losses became heavy.

Their most notorious overseas venture was the Companhia Central Peninsular dos Caminhos de Ferro de Portugal for which they obtained the concession in 1853. Portugal's economy was languishing in the early 19th century, with barely a road worthy of the name, a situation exacerbated by political instability (Freire Costa et al. 2018). In 1845, the then-government established a public works company, but little was achieved beyond some road improvements. In that year 1845, James Anthony Emslie suggested a railway along the Tagus valley towards Spain, and some Portuguese engineers also suggested possible railway routes. Emslie was declared insolvent in 1847, but others were trying to get a concession for a line to Spain.

Following a regime change in 1851, more headway was made, with a route via Santarem to the border at Badajoz. Two British consortia competed for the concession, which involved a guarantee to investors of 6%, but a 1.5% deposit with the Portuguese Government. One comprised Brassey and Peto, with Locke as the engineer. The other was put together by the entrepreneur Hardy Hislop, who already had gas concessions in Oporto and Coimbra, and comprised the Warings, Kitson the locomotive manufacturer, Owens and J.D. Barry, who had previously been involved with the Associated Railway Contractors and a number of Mackenzie and Brassey speculative ventures. Brassey was unhappy with the terms of the concession – particularly the deposit of £10,000 with the government – and pulled out, leaving Warings with a clear field. A modified version of a route surveyed by the engineer Thomas Rumball was approved, and Warings brought in William Shaw, an experienced contractor also from Yorkshire as managing partner. Money was raised on the London capital markets, with nominal company capital of 3.6 m reis (*c.* £800,000), of which one-third

Table 2.1.7 Known Contracts of the Waring Family (Cross-Rudkin et al. 2008; *Bradshaw's Railway Almanack; Economist; Herapath's Railway Journal; Railway Magazine; Railway Times)*

Contractor	*Client*	*Dates*	*Contract*	*Agent etc.*	*Length/Value*	*Engineer*
John Waring	The Birmingham and Derby Junction Railway	1837–1839		With J.T. Leather		R. Stephenson
John Waring	North Midland Railway	1837–1840	North Wingfield		£71,664	G. Stephenson
John Waring	North Midland Railway	1837–1840	Chesterfield	With J.T. Leather	£32,164	G. Stephenson
John Waring	Chester and Crewe Railway	1839–1840				G. Stephenson
John Waring	Manchester and Birmingham Railway	1840–1842	Sandbach		£91,887	G.W. Buck
John Waring	Liverpool Dock Board	1843	Albert Dock excavation			J. Hartley
J. Waring & Sons	Bristol and Exeter Railway	1842	2D, 3D			I.K. Brunel
J. Waring & Sons	Gt Grimsby and Sheffield Jcn Railway	1846–1848	Market Rasen-Lincoln		£73,000	J. Fowler
J. Waring & Sons	East Lincolnshire Rly*	1847–1848	Louth-Boston		£45,639	J. & H. Fowler
J. Waring & Sons	Manchester Sheffield and Lincs Railway	1847–1849	Retford-Gainsborough; Barnetby-Market Rasen		£157,000	J. Fowler
Waring Brothers	Central Peninsular Railway Portugal	1853–1855		With Shaw R. Johnson		J.S. Valentine
Waring Brothers	Graissesac-Beziers Railway	1854–1866			32 miles	
Waring Brothers	Eastern Junction Railway (Belgium)	1855–1862		C.W.R. Chapman		
Waring Brothers	Dorset Central Railway	1856–1860	Wimbourne-Blandford	A. Davis		C.H. Gregory
Waring Brothers	Guillaume Luxembourg Railway	1857–1862	Passerelle Viaduct etc.	C.W.R. Chapman		
Waring Brothers	Norwich and Spalding Railway	1858	Spalding-Holbeach	With Eckersley		
Waring Brothers	Ely Valley Railway	1858–1860			£56,600	
Waring Brothers	Ely Valley Railway	1860–1861	Extension		£13,000	

Waring Brothers	Recife and Sao Francisco Railway	1860–1862		W. Elliot C.W.R. Chapman		M.A. Borthwick C.H. Gregory
Waring Brothers	South Eastern of Portugal	1860–1866		J. Fforde		J.S. Valentine
Waring Brothers	North London Railway	1863–1865	City Branch			W. Baker
Waring Brothers	Lynn and Sutton Bridge Railway	1861–1866			9.5 miles	J. Brunlees
Waring Brothers	Royal Sardinian Railway concession	1863				
Waring Brothers	East Indian/Indus Valley Railway	1863–1867	Jubbulpore Extn	With Hunt; M. Carr, M. Rayne, Nicoll, Brundell, Easton		A.M. Rendel, H. Le Mesurier
Waring Brothers	Peterborough, Wisbech and Sutton Railway	1863–1866				
Waring Brothers	Garston; Liverpool Central Railway	–1866				J. Fowler
Waring Brothers	Bristol Port and Pier Railway	1863–1865			£123,000	J. Fowler Benjamin Burleigh
Waring Brothers	Surrey and Sussex Junction Railway	1865–1869				
Waring Brothers	Kettering, Thrapston & Huntingdon Railway	1864–1866			£230,000	
Waring Brothers	Spalding and Bourne Railway	1864–1866		With Eckersley	£130,000	J. Brunless
Waring Brothers	Northumberland Central Railway	1864–1870	Scotsgap-Rothbury			
Waring Brothers	City of Glasgow Union	1864–1872	Includes St Enoch Station	With Brassey	£2,000,000	J. Fowler and J.F. Blair
Waring Brothers	Orel Vitebsk Rly	1865–1867		J. Fforde	£1.5 m	
Waring Brothers	Midland Railway	1865–1868	4–4 Bedford London*, St Pancras Station			W. Barlow and C. Liddell

(*Continued*)

Table 2.1.7 (Continued)

Contractor	*Client*	*Dates*	*Contract*	*Agent etc.*	*Length/Value*	*Engineer*
Waring Brothers	Solway Junction Railway	1865–1870		With Eckersley A.M. Bell	£320,000	J. Brunlees
Waring Brothers	Metropolitan Railway	1865–1868	Paddington-Gloucester Rd	With Kelk & Lucas		J. Fowler
Waring Brothers	Metropolitan District Railway	1866–1870	South Kensington-Westminster	With Kelk & Lucas T.A. Walker J.S. Okell A.C. Priestley	£1,700,000	J. Fowler
Waring Brothers	LNWR	(1863–) 1867–1868	Sandbach Northwich			W. Baker
Waring Brothers	Belgian Public Works Co/Brussels City	1868–1871	Arching of Senne	J. Fforde		W. Elliott
Waring Brothers	East Hungarian Railway	1868–70?	Klausenburg, Biechnfeld, Kronstadt (Brasov)	With Eckersley; R. Wingate J.M. Burke E.H. D'Avigdor R.S. Clayton C.B. Dunlop H. Hakewell A.J. Hamilton-Smythe	200 miles	
Waring Brothers	Turkish Railway surveys			J.V.S. Muller		
Waring Brothers	Honduras Interoceanic Railway	1869–1881		With McCandish H.H. Leslie W.M. & W.F. Mayes H. O'Hagan	50 miles	
Waring Brothers	Buenos Aires-Valparaiso Railway surveys	186x–1870		J. Fforde surveyor R.S. Clayton		

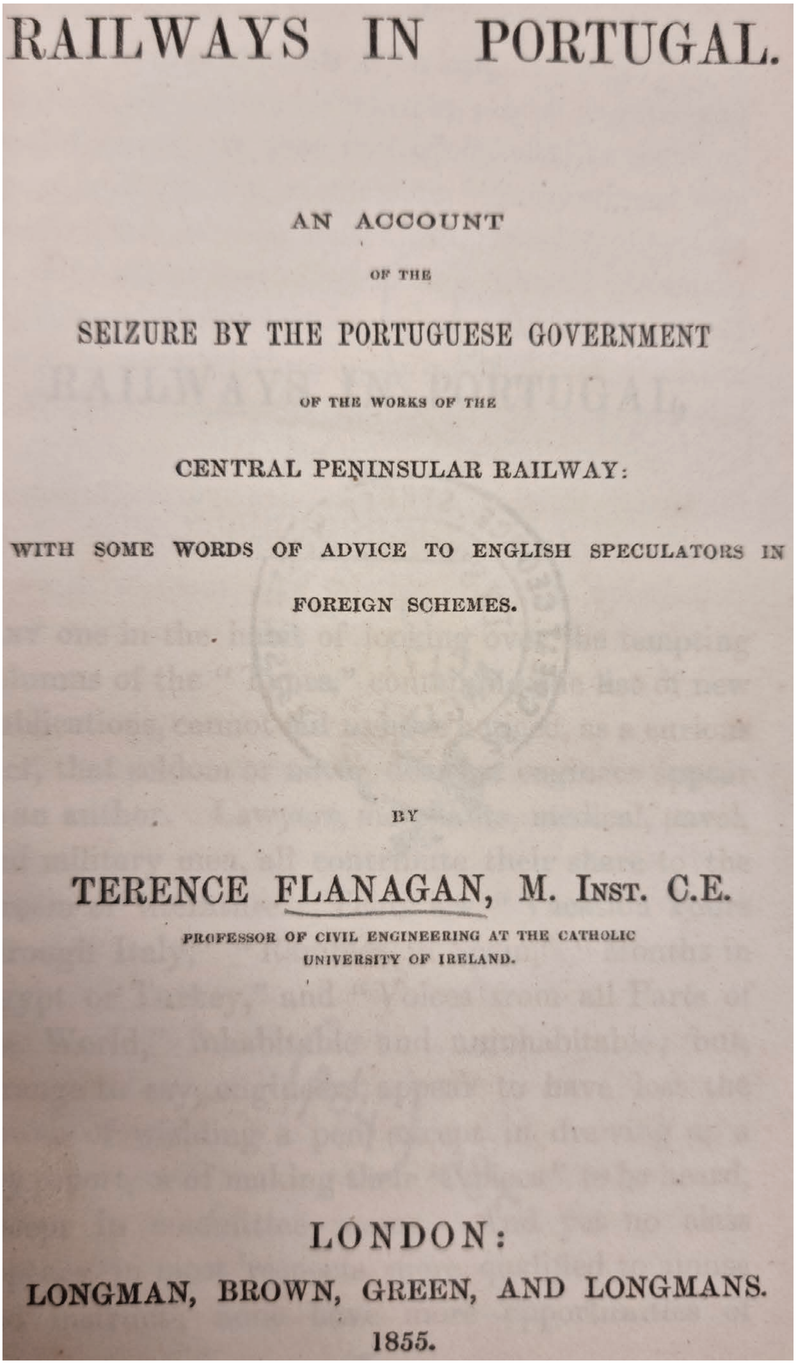
Waring Brothers	Somerset and Dorset Railway			A.C. Priestley H.H. Harker	
Waring Brothers	Central Uruguay Railway	1871–1874 c. 1866–1878		R. Wingate;	195 miles
Waring Brothers	Bavarian Railway	c. 1860			
Waring Brothers	Minas and Rio Railway, Brazil	1880–1884		With H.E. Hunt E.F. Morant H.H. Harker	
Waring Brothers	Vitoria-Natividade Railway surveys	1882–1884		D. Angus	
Waring Brothers	Rio Grande do Sol Railway surveys			J.V.S. Muller	

Figure 2.1.19 Henry Waring, who led Waring Brothers in Europe in the 1850s.

Source: ICE Archives.

had to be raised before work could begin. Work commenced in September 1853. The Portuguese Government were supposed to take one-third of the shares with a further third to be taken by the contractors at a 20% discount, and the remainder raised from the general public. Of the initial 5% deposit (£40,000), there was a shortfall of c. 30% in public subscriptions. This created a problem from the start. The government attempted to persuade the contractors to provide all their share of the capital while withholding payments to them based on the shortfall in the public subscription. The government also tried to reduce the rate per kilometre, effectively reducing the premium on the capital from 3% to 2% and would not honour increase in prices for timber over which the contractor had no control. It was alleged that land prices were corruptly fixed. The government would not pay for goods on their arrival in the ports and would not honour the engineer J.S. Valentine's certificates. The contractors found the situation intolerable, and, although in May 1854, something of a compromise was reached with an agreement to pay them for materials for which the sub grade was ready, in May 1855, the government engineers reduced the value of the engineer's certificate from £16,000 to £4,600, leaving Shaw insufficient money to pay the workforce. In September 1855, the contractors refused to carry on, and in 1857 they were forcibly removed from the work. It was claimed they had only carried out one-third of the work done, yet they had received half of the contract value.

It seems that the government had insufficient capital and the Portuguese had little experience of railway work or construction on this scale; their engineers insisted on the use of hydraulic lime and heavier specification for the bridges and ordered locomotives too heavy for the infrastructure without understanding the implications for the contractors' profit margins. Terence Flanagan, one of the engineers, wrote an account of the affair in which he warned British investors and contractors from undertaking work in Portugal, reproducing the terms of the contract, which he claimed the Portuguese Government had breached (Figure 2.1.20). In truth, it seems neither Shaw nor the Warings suffered significant losses – Shaw left a fortune of £120,000 on his death in 1859, and Warings were competing for a further concession later in the 1850s (Johnson 1858–1862). However, the French working with the Spanish financier Salamanca took on much of the next phase of railway construction in Portugal.



RAILWAYS IN PORTUGAL.

AN ACCOUNT

OF THE

SEIZURE BY THE PORTUGUESE GOVERNMENT

OF THE WORKS OF THE

CENTRAL PENINSULAR RAILWAY:

WITH SOME WORDS OF ADVICE TO ENGLISH SPECULATORS IN FOREIGN SCHEMES.

BY

TERENCE FLANAGAN, M. INST. C.E.

PROFESSOR OF CIVIL ENGINEERING AT THE CATHOLIC UNIVERSITY OF IRELAND.

LONDON:
LONGMAN, BROWN, GREEN, AND LONGMANS.
1855.

Figure 2.1.20 Terence Flanagan's account of the Central Peninsular Railway affair, published in 1855.

Source: ICE Archives.

Warings were not put off by the episode and with other partners and support from the British financial markets were involved in schemes in Brazil and Argentina, Austria-Hungary, Italy and India. They used a number of partners and trusted subordinates, often with local knowledge. Thus, for the Jubbulpore contract on the East Indian Railway (1862–1867), they were in partnership with James Hunt, who had already been contracting in India. The Railway Company employed 26 engineers to supervise the contract, and the contractors matched this, with Mark Carr (who had worked as an engineer on earlier Indian lines); George Nicoll, who had worked under Hunt; and Richard Shaw Brundell and John M. Easton who took on the maintenance contract on completion. There was a vigorous debate in India over the use of contractors rather than direct labour and management by the Public Works Department engineers and some contractors with little knowledge of local conditions struggled to make a profit, but both Brassey and Warings seem to have been successful, being mindful of local contacts (Kerr 1995).

Their experience in Europe made Warings obvious participants in two consortia intended to take advantage of the growing demand for public works there, possibly inspired by the scale of work being undertaken by the Metropolitan Board of Works in London. It is not clear that anything came of their involvement in the Anglo-French Company, established in 1865 to build municipal works in Paris; it almost certainly was a victim of the Overend–Gurney crash as it also involved Peto and Betts (*Railway Times* 1865: 1253).

The Belgian Public Works Company was set up to deliver controversial improvements in Brussels inspired by the work of Haussmann in Paris, centred on the culverting of the River Senne with associated road improvements (*Economist* 1866: 1599). The firm was successful in obtaining the contract for the work, although it was enmeshed in a scandal prompted by the embezzlement of some of the funds by a British director. William Elliott (1827–1892) who had worked for Warings in Brazil was engineer for construction, and long-term associate James Fforde (1836–1907) was agent (Figure 2.1.21) (Fforde 1866–1871). The city took over the work in 1871 along with responsibility for the central boulevard project that shaped modern Brussels (Demey 1990).

Warings did not take on a contract with the Metropolitan Board of Works for the Main Drainage scheme of London, a project on which "modern" forms of contracts were effectively

Figure 2.1.21 Arching of the Senne in Brussels in the late 1860s.

Source: Wikimedia Commons.

standardized (Royal Commission 1888) but were part of the consortium with Brassey responsible for the associated work on the Metropolitan District Railway between South Kensington and Westminster, with Thomas Walker as agent. The Editorial of the *Railway Times* treated the news of the involvement of the consortium with the work with faint praise: "The powerful organisation known to embrace the names of Peto, Betts, Kelk and Waring has no great charm for us" (*Railway Times* 1866: 11 February 168).

Warings, like many larger UK contractors, promoted "contractors" lines – railways where contractors helped raise the capital for construction, receiving discounted shares on favourable terms against which they could raise bonds and loans to finance construction. A typical criticism was that they were devised by contractors to force existing companies to buy them out at a profit to them as promoters. The reality seems to be that without contractors taking much of the initial risk, many lines would not have been built (Pollins 1957–58; Cottrell 1975b; Cross-Rudkin 2016). On occasion, they offered to run the railway on completion for a number of years at an agreed rate of return. Such methods were common after the railway mania bubble burst in 1847–1848, but it is evident from the affairs of Mackenzie and Brassey that contractor's financial engagement was significant from the early 1840s. In 1848, *Herapath's Railway Magazine* complained about the lack of competition in tendering and a growing tendency for contractors to tender for the whole line, and from 1838 "a small body of men, often acting in combination [. . .] had begun to hold quarterly meetings" (Killett 1969).

In 1864, Charles Waring (Figure 2.1.22) negotiated on behalf of Brassey and others the terms of the agreement between the City of Glasgow Union Railway and the contractors by which the contractors took on all the work with a guarantee of a 10% profit, in return for which they agreed to take up the capital not taken up by the public (Bradshaw 1869). On the Bristol Pier and Railway Company, Warings were to work the line for years, paying dividends at 2.5% in the first year, increasing to 5% in the sixth year, evidently assuming there would be profits beyond this to justify their investments. Work in Brazil was undoubtedly encouraged by the prospect of a government guarantee of 7%. Charles Waring and his brothers frequently found themselves on the boards of railways even when they had not been the contractors, particularly with various East Anglian lines; this had not been a usual feature of railway boards before 1860 (Hodgkins 2019). Perhaps Warings' most notorious venture into "contractors' lines" was their involvement in the Dorset Central Railway and Somerset and Dorset Railway, promoted as means of linking the Bristol and English Channels, but with limited prospects of heavy traffic.

This activity became associated with Charles Waring's attempts to become the Liberal MP for Poole, and the promotion of the Poole and Bournemouth Railway Act in 1865. Waring was successfully elected in that year despite being libelled by his opponent, whom he successfully took to court. The financial situation led him to sell the family shares to the London and South Western Railway which thereupon halted plans for construction. The local electorate may have felt manipulated and voted him out in 1868; a successful campaign in 1874 was overthrown following allegations of improper electoral conduct.

Some idea of the scale of Waring Brothers' enterprise and the numbers of site staff they employed can be gained from Table 2.1.7. This excludes office staff like their estimator Conrad Abben Hanson and J.S. Okell. It is clear that Warings worked with a number of engineers and similarly a number of financial houses – the Union Bank in Portugal, De Mornays on the Recife (Pernambuco) Railway and Credit Foncier on the Senne. In the 1860s, Warings were heavily involved in bodies such as the London Financial Association which provided finance for railway in East Anglia; here and elsewhere Warings' partner was William Eckerlsey. Several of their schemes involved Baron Albert Grant (Abraham Gottheimer) (1831–1899), well known as a

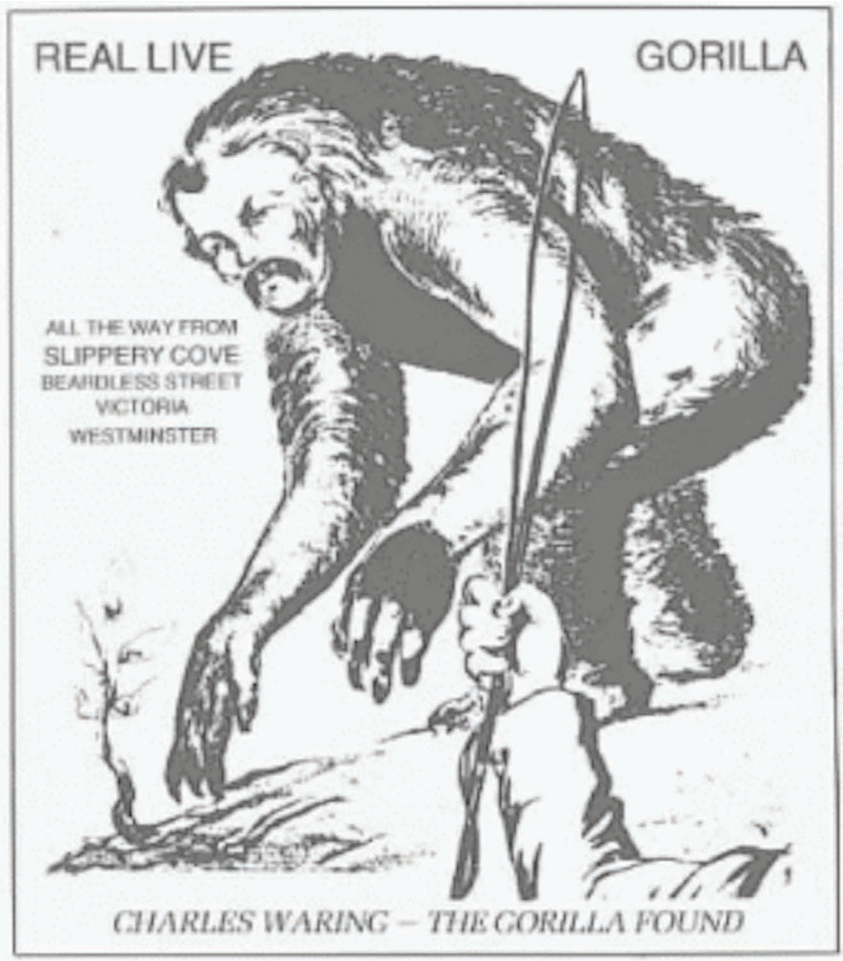


Figure 2.1.22 Charles Waring was the most dynamic and successful of the Waring Brothers, but a subject of much controversy as seen in this cartoon, inspired by his machinations to become Poole's MP.

Source: Frank Smith collection, ICE Archives.

promoter of companies in the third quarter of the 19th century, including the Belgian Public Works Company and the Central Uruguay Railway.

At times immersed in controversy, Charles Waring nevertheless clearly proved capable of amassing a fortune from railway speculation and construction. This was not simply a case of contractors' lines and foreign ventures, but works for substantial companies like the Midland Railway (Figure 2.1.23). His affairs, like those of Thomas Brassey, are worthy of further study. With apparent losses on a number of projects, the profit margin on the successful contracts meant Waring Brothers were in business for around 50 years, seemingly without the advantage of mining or manufacturing interests that sustained the likes of Brassey, Wythes and David Davies. These businesses were far larger than the members of the Master Builders' Association described by Cooney (Cooney 1980: 157).

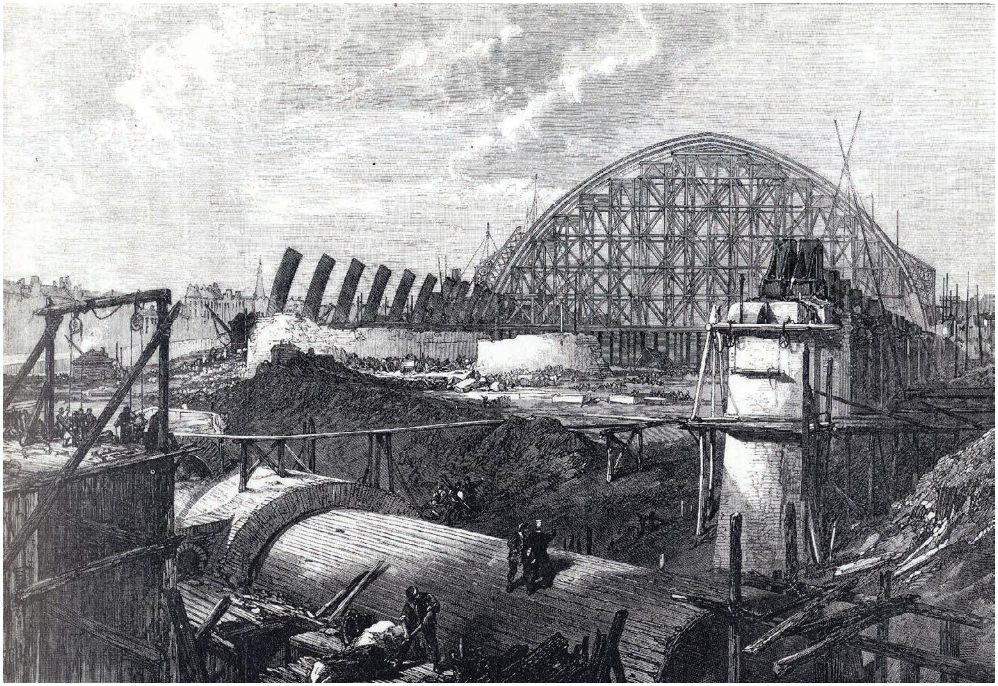


Figure 2.1.23 London St Pancras Station under construction in the 1860s, one of a number of major contracts undertaken by Waring Brothers; the ironwork for the station was a separate contract with the Butterley Company.

Source: *Illustrated London News* (1868) 15 February, ICE Archives.

The Complete Picture

Construction historians inevitably concentrate on the construction achievements and perhaps the business successes of contractors, overlooking other interesting aspects of their lives. Given the wealth that some leading contractors acquired, their outside interests may also well be worth examining. In that respect, the university-educated David McIntosh is an outstanding early example, possessing as he did a fine collection of old masters in his home (Christie's 1857).

Perhaps less surprising was William Mackenzie's commissioning of art works celebrating his construction achievements, in a way similar to Thomas Telford (Figure 2.1.24). Both of these figures, like many leading engineers and contractors of the time, were the subjects of portraits – often paid for by their admiring peers. Mackenzie's partner Thomas Brassey was the subject of several such works. However, there is no indication that Brassey collected artworks beyond those required to furnish his homes. The same was probably true of many of his contemporaries who acquired large rural piles (Figure 2.1.25).

However, among late Victorian contractors, the most astounding example of the contractor as patron of the arts is Sir John Aird, known as "St John of the large heart" by the artistic community. There is some evidence that he competed with his partner Thomas Lucas as a patron of the arts. Not only did Aird commission a large number of paintings, he also included a private theatre in his West End home. An article in the *Art Journal* gives a fascinating portrait of his

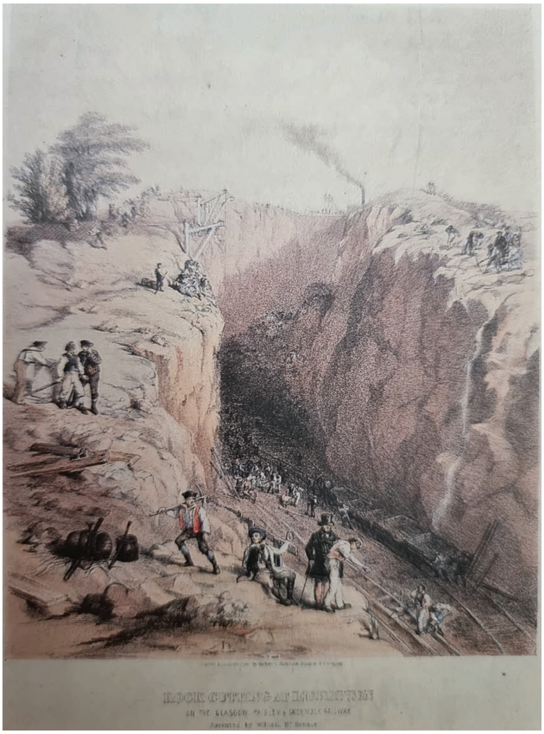


Figure 2.1.24 William Mackenzie inspecting his works at Bishopton cutting for the Glasgow Paisley and Greenock Railway in 1841.

Source: Elton Collection, Ironbridge Gorge Museum Trust.

Figure 2.1.25 Somerleyton House, the former home of Sir Samuel Morton Peto. Peto commissioned a number of paintings by John Lucas.

Source: Morris (1866–1880).

collection and life at home, surrounded by the works of many late Victorian painters, who were out of fashion for much of the 20th century (Figure 2.1.26).

It is difficult to understand today how Aird's family full of daughters might have felt about works like Tadema's *The Roses of Heliogabalus* (1888) adorning the walls, raising questions about present-day attitudes to works of art and challenging how we can judge collectors like Aird in the round. We should not be surprised by this ostentation of wealth, but for some engineers, the paintings were clearly more than expensive wallpaper. According to Dianne Sachko-Macleod in her study of Victorian patronage of the arts by middle-class Victorian businessmen, this was a significant part of the affirmation of a distinctive class identity (Sachko-Macleod 1996: 2). An impression of the good life of the Victorian contractor abroad can be seen through the life of Charles Henfrey (1818–1891). With a construction background, he and his brother George went to Italy in 1851 to work on Brassey projects for the Sardinian Government. Charles

Figure 2.1.26 Sir John Aird's art-festooned home at 14 Hyde Park Terrace, c. 1890.

Source: ICE Archives. *Art Journal* (1893) xliii, 135–140.

proved to be an able society diplomat as well as project manager. In 1858, Brassey, Wythes and Joseph Paxton of Crystal Palace fame won the lump-sum contract for the East Bengal Railway. A competent agent was required, and Charles Henfrey, with his Outram family connections, was an obvious choice. He and his wife became part of the Calcutta expatriate social scene.

While his brother was in India, George remained in Italy, developing a close relationship with Cavour, and leaders of the Risorgimento, hosting meetings at his villa beside Lake Maggiore. He managed the large industrial concerns which he and his brother had invested in with Brassey.

The Eastern Bengal railway was not particularly profitable, but Charles had learned how best to take advantage of Indian labour and subcontractors, and he took on the management of even larger projects for Brassey. The completion of the Delhi Line marked the end of Henfrey's professional career, perhaps because it closely coincided with Brassey's death. He joined his brother in Italy and commissioned a villa on Lake Maggiore (1871–1873) (Figure 2.1.27). Here he hosted visits from Queen Victoria in the spring of 1879 and the Crown Prince, later Kaiser Frederick III of Germany, in 1883. He built up a collection of artworks, including works by old masters like Titian, and this was added to by presents from his visitors including a marble bust of Queen Victoria. He also built a villa, the Chalet des Rosiers, at Menton, in 1880, where the Queen stayed, establishing the Riviera as a fashionable destination for the upper classes.

Nothing has been said about the role of women in public works contracting of the time, although some background can be obtained from the diaries and biographies of Mackenzie and Brassey. The only known instance of a woman taking on the responsibility for project delivery is Alice Tredwell, who fulfilled her husband's contract on the Great Indian Peninsular Railway out of Mumbai following his death (Figure 2.1.28).

Figure 2.1.27 Villa Henfrey on Lake Maggiore.

Source: The author.

Figure 2.1.28 Bhore Ghat incline on the Great Indian Peninsular Railway, contractors Solomon and Alice Tredwell.

Source: ICE Archives.

Conclusion

From the mid-18th century, it became possible for masons, carpenters, materials suppliers and organizers of manual labour in the British Isles to make a continuous living out of the construction of public works. These works, often privately funded, were being undertaken on a larger and more frequent scale than in previous generations; as expertise grew, so could profits, and by the early 19th century, large general contractors had emerged. This took place against the background of agricultural and industrial revolutions where increased mechanization in – for instance – the textile industry and new technologies such as coal gas lighting and the steam locomotive saw a step change in economic growth and the opportunities for speculative finance. In the second quarter of the 19th century, some contracting enterprises started operating on a European and then global scale, their leaders rubbing shoulders with politicians and royalty. Demand for their services was based partly around the desire of investors to have reliable contractors capable of delivering the public works their companies were responsible for, but also for their access to finance and British financial markets. Contractors developed within a century from small local enterprises only able to take on individual bridge or lock contracts to million-pound concerns capable of financing the construction of whole railways, with interests in associated material and rolling stock supply. The financial background was altered by the collapse of the Overend–Gurney Bank in 1866, which required an adjustment to the financial model used by many of the larger contractors, while many of the first generation of Victorian contractors were coming to the end of their careers around 1870 (Floud et al. 2014; Schneider 2022). That date, with the death of Thomas Brassey at the end of the year, provides a convenient end to this chapter. The last quarter of the century saw an enormous increase in British overseas investment, which the upcoming generation of public works contractors were able to take advantage of, as well as a growth in municipalization–public investment in tramways, water supply and sewerage, gas and electricity supply, providing more variety of work within the UK as well as overseas.

While some research has been done on the contractors of the 18th century, more can be done to establish their typical size, sources of finance and profitability, putting substance on the skeletons of their lives derivable from parish records and minute books. Such work remains slow as it has to be done locally. For the 19th century – and indeed more recently – similar questions remain, but the volume of material is much greater, with the financial and technical press in addition to archives. Many record offices contain records of local builders as well as the solicitors who serviced them and their clients, while some important records have been deposited at the Institution of Civil Engineers and the Metropolitan Archives relating to Mackenzie and Brassey and John Mowlem (Figure 2.1.29).

These resources have barely been investigated, and most publications have concentrated on the well-known names of the railway age, for whom contemporary biographies exist. Of the best-known, Samuel Morton Peto, Sir John Jackson and William Dargan have had recent biographies, but the enterprises of George Wythes and Waring Brothers surely warrant more study. While it is relatively easy to identify works with which they were involved, their financial relationships and management structures are more difficult to establish. And surely, given the scale of his enterprise, Thomas Brassey warrants an international collaborative research project. Did a multi-million-pound enterprise, the Victorian equivalent of Amazon or Google, really disappear in December 1870? It seems unlikely. Beyond that, what differentiated a profitable enterprise from an unprofitable one: was it really to do with good estimating and financial control, and a simple profit and loss on each project (Figure 2.1.30) or more to do with a firm's ability to "contract" to provide a means of selling other goods and services which were more profitable than the actual construction job itself? One suspects it was the latter.

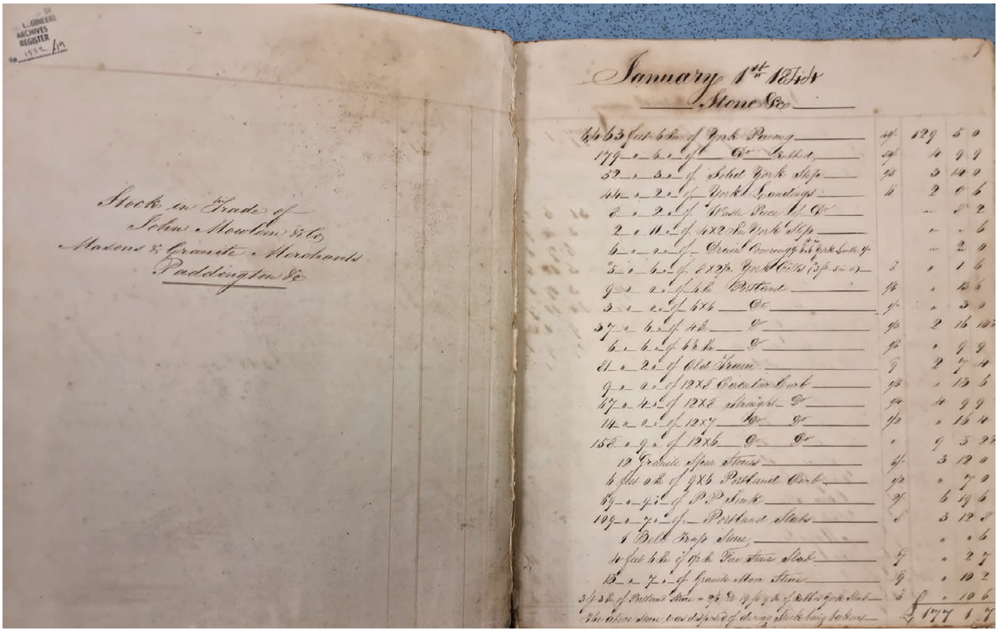
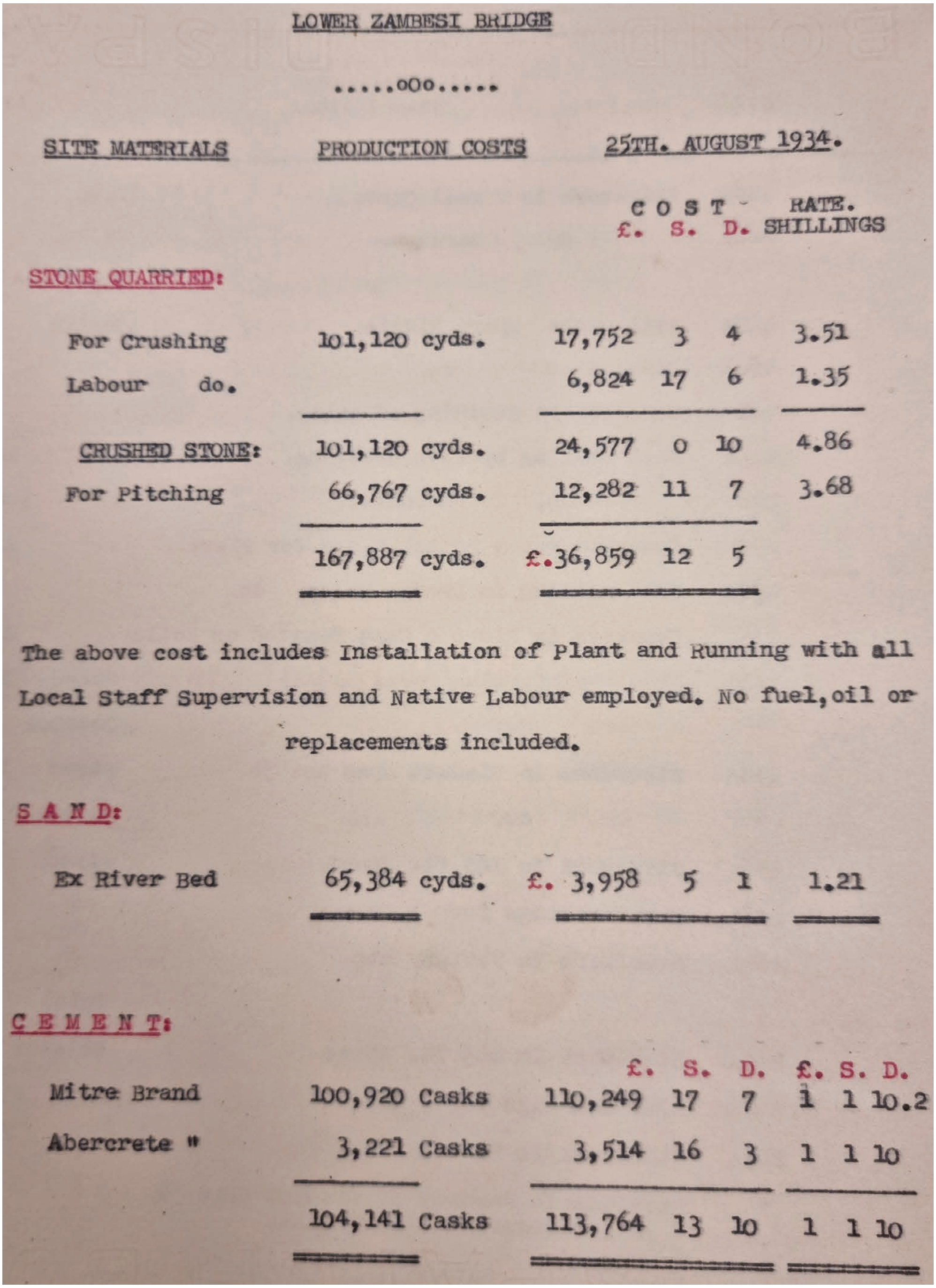


Figure 2.1.29 Stock book of John Mowlem.

Source: ICE Archives.



LOWER ZAMBESI BRIDGE

.....ooo.....

SITE MATERIALS PRODUCTION COSTS 25TH. AUGUST 1934.

		COST £.	S.	D.	RATE. SHILLINGS
STONE QUARRIED:					
For Crushing	101,120 cyds.	17,752	3	4	3.51
Labour do.		6,824	17	6	1.35
CRUSHED STONE:	101,120 cyds.	24,577	0	10	4.86
For Pitching	66,767 cyds.	12,282	11	7	3.68
	167,887 cyds.	£.36,859	12	5	

The above cost includes Installation of Plant and Running with all Local Staff Supervision and Native Labour employed. No fuel, oil or replacements included.

		£.	S.	D.	RATE
SAND:					
Ex River Bed	65,384 cyds.	£. 3,958	5	1	1.21

CEMENT:		£.	S.	D.	£.	S.	D.
Mitre Brand	100,920 Casks	110,249	17	7	1	1	10.2
Abercrete "	3,221 Casks	3,514	16	3	1	1	10
	104,141 Casks	113,764	13	10	1	1	10

Figure 2.1.30 Cleveland Bridge Company Accounts for Lower Zambezi Bridge. Records such as these, giving details of the profits on a construction project, are rare indeed.

Source: ICE Archives.

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Chapter 2.2

The Belgian Company Blaton

From the Trade of Cement to the International Promotion of Prestressed Concrete, 1865–1954

Bernard Espion, Rika Devos and Michel Provost

The Blaton Archive

In 2013, about 70 m^3 of various documents were donated by a descendant of the Brussels entrepreneurial family Blaton to the Archives of Modern Architecture – CIVA Foundation in Brussels.[1] These documents came from the basement of the building located in Schaerbeek, owned and used by the Blaton company, or by companies that were directly derived from it, as of 1876. The authors, after a very preliminary exploration of this mass of documents, planned to engage in a first description and analysis of the findings, which led to the publication of some targeted and limited contributions, as well as a book in 2017. A comprehensive overview of the history of this enterprise has never been published in English until now: that is the purpose of this chapter.

The reason for the authors' interest in this archive is the following. First, they knew that the company Blaton had played an important role in the history of construction in Belgium as a contractor of public and private works, especially in the field of construction using concrete. Moreover, it is very rare to find archives of construction companies – as well as archives of engineers – because they are very often destroyed after the legal conservation period (10 years only) or when companies disappear (through merger, absorption, bankruptcy or liquidation) or simply move. Here, we are talking about a company initially created in 1865 which, after multiple divisions as the baton was passed from generation to generation, still exists today and is managed by a direct descendant (fifth generation) of the company's founders.

The content and form – as well as the condition – of the documents kept in this archive vary greatly. Most of them are bound documents, numbered or not, packaged or not according to the rules of art. Some of the files were slipped into an envelope at the last minute, using the plans for another major project as wrapping paper. The files bring together different types of documents: contracts and correspondence; bids; preliminary studies; architects', engineers' and the company's own plans; quantities and specifications; calculation notes; technical documentation; patents; prices and accounts; list of materials; workers' services; site reports; newspaper clippings and so on. For certain well-documented projects, rolls of plans have also been kept, some of which are fragile. There are at least as many – if not more – files concerning projects studied but not followed by Blaton as projects carried out by the company. The archive also includes a fairly large collection of photographs, isolated shots, sometimes annotated or sorted by project in envelopes, but also albums that can be considered the company's portfolio. The oldest of the photographs can be dated to 1895. There was initially no inventory of the documents, and it was far from complete in 2015 when the authors stopped working on this archive.

The archive papers total 255 m in length, of which 115 m relate very specifically to the Congolese subsidiary of Blaton from 1949 to 1975. These files concerning Africa were immediately separated

DOI: 10.1201/9781003368656-12

from the others and were the subject of a quick inventory (Van Craenenbroeck 2015) and then used in a specific research project.[2] The remaining 140 m almost exclusively cover the period 1905–1954, and especially the period 1919–1954, which was particularly well represented and proved to be rich in discoveries. The archive does not therefore cover all the company's activities, and for the years 1865–1905, it was necessary to reconstruct the general activity of the company by exploiting other sources, such as information and advertisements published in the press. Finally, it should be noted that during the whole period under consideration, Blaton was a family business, managed by the family: it was not accountable to shareholders outside the family, decisions were taken by the owner(s) of the company and they did not communicate their turnover or their assets. The archive does not include any minutes of meetings of the board of directors or of the general meetings of the shareholders.

The documents in the archive complement existing knowledge within the history of architecture in Belgium. But their importance to the history of construction and civil engineering in Belgium is likely to be even greater.

A Dynasty of Builders

The Blaton-Aubert company was created in Brussels in 1865 by Adolphe Blaton (1835–1905) and his wife Adèle Aubert (1838–1903). It was then a business selling building materials – mainly lime, plaster, different types of cement and trass. It is worth remembering that no artificial cement was produced in Belgium before 1872, when Portland cement was necessarily imported. Blaton-Aubert also specialized in the use of artificial cement – a novelty material at that time – for hydraulic works such as building cisterns or sealing cellars. Finally, the company also made artificial concrete rockworks to decorate gardens and public spaces, although no examples of this activity are known before 1875 (Espion 2017). In 1876, the Blaton-Aubert company moved into industrial buildings in Schaerbeek that allowed it to prefabricate small concrete products, which were exhibited – and noted – at the Paris International Exhibition in 1878 (Figure 2.2.1).

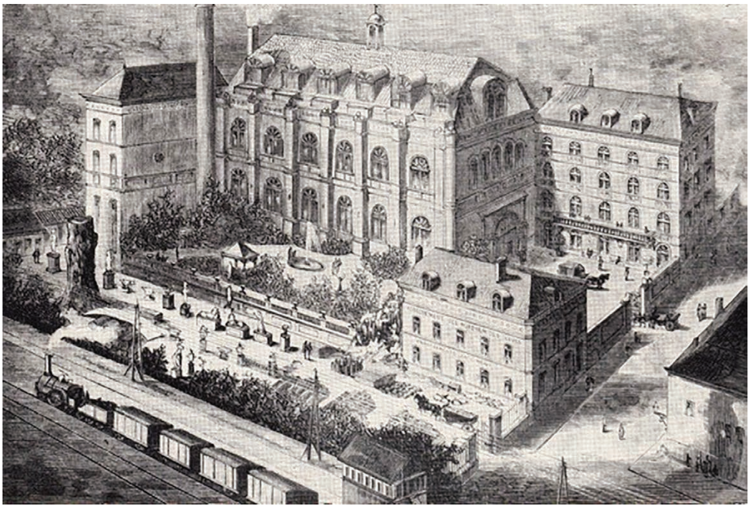

Figure 2.2.1 The Blaton-Aubert factory and company headquarters in Schaerbeek (Brussels) around 1880.

Source: Advertising material printed by the company, Blaton Archive, Fondation CIVA.

This period also saw production begin on moulded concrete copies of ancient statues, which were particularly praised by attendees and experts at the exhibition organized in Brussels in 1880 to celebrate the 50th anniversary of the independence of Belgium. In 1883, businessman and philanthropist Adolph Sutro (1830–1898) purchased nearly 200 cast concrete pieces from the Blaton-Aubert catalogue to decorate his property overlooking the Pacific Ocean in San Francisco (Sutro Heights), which was open to the public (Figure 2.2.2).

In the 1880s, another important prefabricated product from the company was the concrete pipe. Blaton used this product for sanitation works, for water distribution and sewage in several cities in Belgium (Espion 2017; Espion & Pesztat 2017).

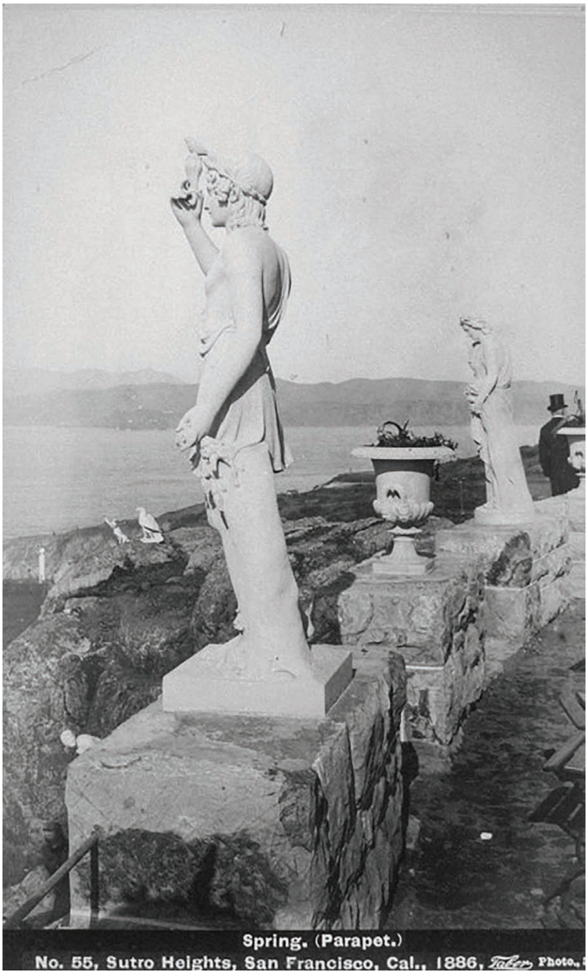

Figure 2.2.2 Concrete statue of the Spring at Sutro Heights, California, with the Golden Gate in the background. The man in a top hat is Adolph Sutro.

Source: Photograph by I.W. Taber, 1886, BANC PIC 1983.117 – ALB, The Bancroft Library, University of California, Berkeley.

Adolphe Blaton and Adèle Aubert had two sons: Armand J. Blaton (1863–1929) and Jules Blaton (1874–1948). Around 1890, the family business seems to have come under the management of Armand Blaton who renamed it Ciments & Bétons. It was Armand Blaton who developed the company's general contracting activity and brought it into the era of reinforced concrete around 1897. Armand's brother, Jules, gradually took on the management of the company. But around 1905, the year their father died, Armand and Jules separated their activities. Armand stayed on in the historical buildings in Schaerbeek which housed the prefabrication and production workshops of the famous statues, but renamed the company Armand Blaton, successor of Blaton-Aubert and Ciments & Bétons. Very quickly, this company advanced significantly in the field of civil engineering works and industrial and private constructions in reinforced concrete everywhere in Belgium. Meanwhile, the company created in 1908 by Jules Blaton seems to have remained a more modest company, essentially focusing on the construction of concrete frame buildings, and especially in Brussels. Its catalogues of 1908, 1909 and 1910 – the only ones known to us – still proposed the supply of the concrete statues which were the reason for Blaton's fame since 1878. The last works of this company of Jules Blaton appear to date from the 1930s.

Armand J. Blaton and his wife Eugénie Peyralbe (1872–1938) had two daughters and two sons: Armand E. Blaton (1897–1988) and Émile Blaton (1902–1970). In 1927, the brothers Armand and Émile took over the management of the general contracting company, which changed its name once again: from 1927 to 1932, it was called Compagnie Industrielle de Travaux – Industra; then, in 1932, it was renamed Blaton-Aubert. We will see that the brothers Armand and Émile created several specific companies – not only for commercial reasons but also to embark on a new activity: real estate development.

Armand had four sons and Émile two sons and a daughter. In 1954, it was time to think about passing on the family company Blaton-Aubert to the fourth generation. Armand and Émile shared their clients, and in 1954, Armand created the company Bâtiments & Ponts involving his two older sons, Ado (1926–2002) and Jean (1927–2020) as partners. Émile created the Compagnie Industrie et Travaux which became CITEB, then CIT Blaton, a company which still exists today (2022) and which is chaired by Émile's granddaughter. As the archives stop around 1954, this chapter will only cover the activities of the Blaton companies until about 1954.

Blaton and Technological Innovations

The company Blaton-Aubert (1865–*ca*. 1890) seems to have been innovative in Belgium in the use of artificial cement as a binder for mortars used in waterproofing works. From 1876 onwards, it was the champion in Belgium of large-scale prefabrication of concrete products by moulding and compression in its Schaerbeek workshops. It popularized in Belgium the term "agglomerated concrete" (or rammed concrete), which is a very explicit reference to the promotion of concrete in France by François Coignet (Richaud 2018). There is no evidence to suggest that Adolphe Blaton met Coignet or had a licence for his patents. Nevertheless, it cannot be ruled out that Adolphe Blaton was inspired by Coignet's writings and achievements, or that "agglomerated concrete" had simply become synonymous in the 1880s with what would be called simply "concrete" a little later. Furthermore, the composition of the agglomerated concrete produced by Blaton was very different from "Coignet-agglomerated" concrete, since it contained no slag.

Notwithstanding, in the 1890s, the company Ciments & Bétons was rather late in seizing the opportunity to develop reinforced concrete. In those years, the Hennebique system and its network of agents were quite hegemonic in Belgium (see Chapter 1.6 in this book). Despite what some of the company's advertisements say, it seems that there was never a Blaton system of reinforcement layout; on the contrary, Blaton used steel strip stirrups at the beginning, which gave rise to disputes of priority between him and Hennebique (Baes 1932: 652). The delay and differentiation from Hennebique and his agents in Belgium were already resolved by Armand Blaton in 1905 (at the latest).

Armand Blaton also had the opportunity to compete with Hennebique in the field of concrete foundations. Like Hennebique a little before him, Blaton produced some of the earlier precast reinforced concrete piles (Espion & Hellebois 2017). But these piles have a big disadvantage: when a prefabricated pile is driven to refusal, the section above ground, which has become useless, must be re-cut (Figure 2.2.3).

Therefore, early in the history of concrete construction, inventors devised techniques to cast concrete piles directly into the ground (Hellebois et al. 2012). In 1902, Hennebique introduced the Compressol system of cast-in-place piles invented by Dulac. Armand Blaton soon followed

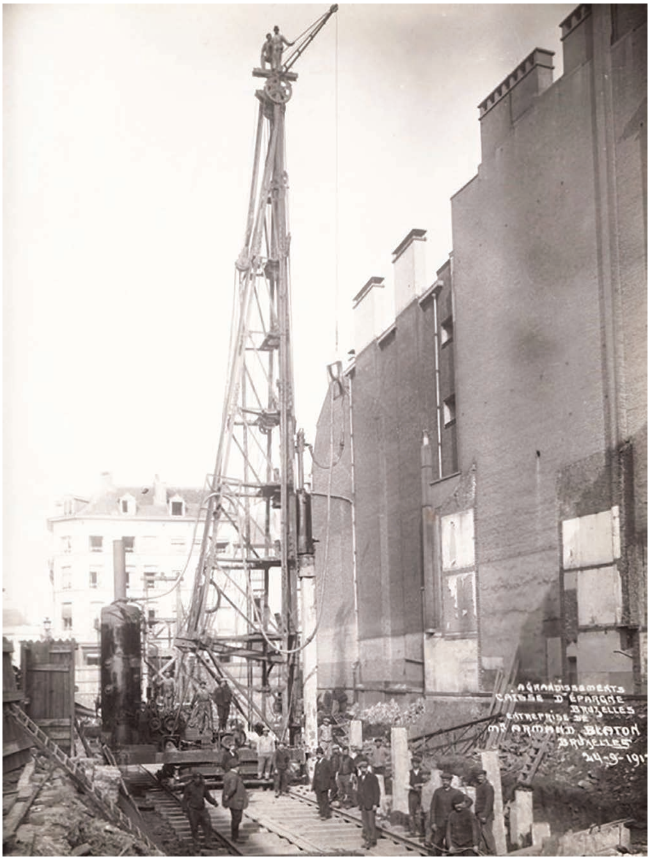

Figure 2.2.3 Driving prefabricated reinforced concrete piles for the foundations of the extension of the Caisse d'Epargne savings bank in Brussels (photograph dated 24 September 1912).

Source: Blaton Archive, Fondation CIVA.

this trend: his catalogue dated about 1905 indicates that he was the only representative for Belgium of the Simplex pile system (Figure 2.2.4), patented in Philadelphia in 1903 by engineer-inventor Frank Shuman (1862–1918). This does not mean that the prefabricated pile was abandoned: Figure 2.2.3 shows that it was clearly still in use in 1912. The choice between cast and precast piles was informed by the specific technical, practical and economic circumstances.

The development of the Franki pile from 1910 (see Chapter 6 in this book) forced Armand Blaton to react. In 1912, he filed a Belgian patent for a pile moulded in the ground, which seems to be just a refinement of the Simplex pile, but which he marketed with great publicity under the name of Robur pile. This system was used extensively by the company until 1927.

In 1927, in parallel with the continuation of the general contracting activities of the Armand Blaton company in the new company Industra, the brothers Armand E. and Émile Blaton created the company Pieux Vibro whose object was to exploit – for Industra or competing contractors – the implementation of the concrete pile casting process patented in 1921 under the name of “Vibro concrete pile” in London by the engineer Alfred Hiley. This process was able to compete effectively with the Franki system (Figure 2.2.5). The company Vibro Piles carried out numerous pile-loading tests for experimental purposes, for the development of the process and equipment or for promotion. A promotional brochure for the Pieux Vibro process published around 1944 mentions 164 cases (sites where Vibro piles were used in Belgium or in France) since 1927 (Espion & Hellebois 2017). Its activity lasted at least until the 1960s.

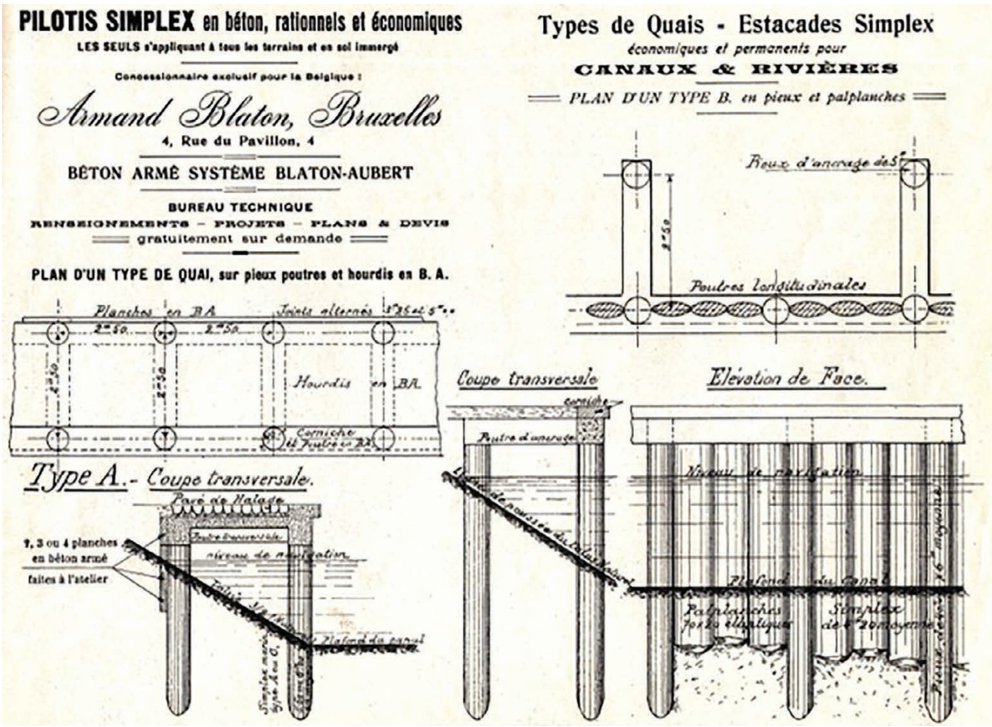

Figure 2.2.4 Armand Blaton advertises that he is the sole licensee for Belgium for the Simplex pile.

Source: Page from an advertisement brochure of the Armand Blaton company dated *ca.* 1905, Blaton Archive, Fondation CIVA.

Figure 2.2.5 Execution of Vibro cast *in situ* piles for the foundations of a Boulevard Pacheco office building (Brussels) in 1961.

Source: Archives CITEB.

Unquestionably, the most innovative and the most striking step undertaken by Blaton-Aubert was to enter the field of prestressed concrete. On the eve of the Second World War, the only known and published applications of prestressed concrete were those by Eugène Freyssinet in France and Algeria and by his licensee Wayss & Freytag in Germany for the pre-tensioning process and some very particular applications in external prestressing by Franz Dischinger and Ulrich Finsterwalder in Germany (Espion & May 2020). The patents related to prestressed concrete construction (1928, 1939, 1940) filed by Eugène Freyssinet in many countries, as well as his network of representatives abroad, made it very difficult to apply prestressed concrete without using his technology or paying him royalties. In Belgium, Professor Gustave Magnel (1889–1955) of the University of Ghent began to take an interest in prestressed concrete technology around 1941 (Espion 2015), or perhaps even slightly earlier. But prestressed concrete is not a process that can be developed in the laboratory: it needs to be experimented with in real life and under real site conditions. This is why Gustave Magnel teamed up in 1941 with Blaton-Aubert to start developing and promoting the technique in Belgium. France had been attacked by Germany in September 1939, and Belgium was swiftly invaded in May 1940. Construction activities did not completely cease in Belgium, but they came under strict controls regarding the use of materials (cement, steel) which were subject to quotas. In principle, prestressed concrete allows substantial savings on materials (concrete, steel, formwork wood) compared to reinforced concrete, as well as increased construction speed thanks to prefabrication. It was therefore in Blaton's interests to apply this new construction method quickly. Moreover, if Blaton could manage to obtain contracts for works based on this new technique, he could retain his workers in Belgium rather than see them leave for Germany under the Forced Labor Service (Devos & Espion 2018).

The beginnings of prestressed concrete in Belgium during the war have been detailed elsewhere (Espion 2015; Espion & Hellebois 2017; Espion & May 2020) and will not be retold here. A few points are worth recalling, however:

- Initially, Magnel only wanted to do full-scale experiments with the technology of prestressing by post-tensioning developed and patented by Freyssinet in 1939. However, the war conditions during this period did not allow the components (anchorages, jacks, etc.) of the Freyssinet system to be imported from France to Belgium. Thus, from 1942, Magnel and Blaton therefore developed a "national" prestressed concrete technology called Blaton-Magnel or "Sandwich" (Figure 2.2.6), but which fell within the scope of applications and means covered by Freyssinet's patents. It was therefore necessary for Blaton to notify Freyssinet of the applications of the Sandwich system in Belgium and to pay him a royalty for its use (Espion 2015). This remuneration system lasted at least until 1946.
- From 1941 to 1944, Blaton and Magnel collaborated closely on the development of this technology, carrying out several projects and prospecting the market in Belgium. In contrast to France, where Freyssinet was opposed to this principle, many applications in Belgium were by external prestressing (Espion & May 2020).
- During the occupation, there were few prestressed concrete projects using the Freyssinet technology in France, and in 1945, only two operational technologies of prestressing by post-tensioning could enter the international market of reconstruction of infrastructures destroyed by the war (especially bridges): the French Freyssinet technology and the Belgian Blaton-Magnel technology. Freyssinet was the best internationally known French engineer at that time, but Magnel had three other assets: he was fluent in English, welcomed many visitors and trainees from abroad in his laboratory in Ghent and wrote the very first book on prestressed concrete design published in 1948, in French and English.

Between 1942 and 1953, Blaton filed patent applications for the Sandwich cable in no less than 23 countries. In May 1950, Armand E. and Émile Blaton created the limited company Le Câble Sandwich to exploit these patents in Belgium and abroad. In 1947, Blaton-Aubert introduced cables (tendons), and anchoring devices for 7-mm diameter wires, before Freyssinet did the same with his system. Such innovations made it possible to exert twice as much prestressing

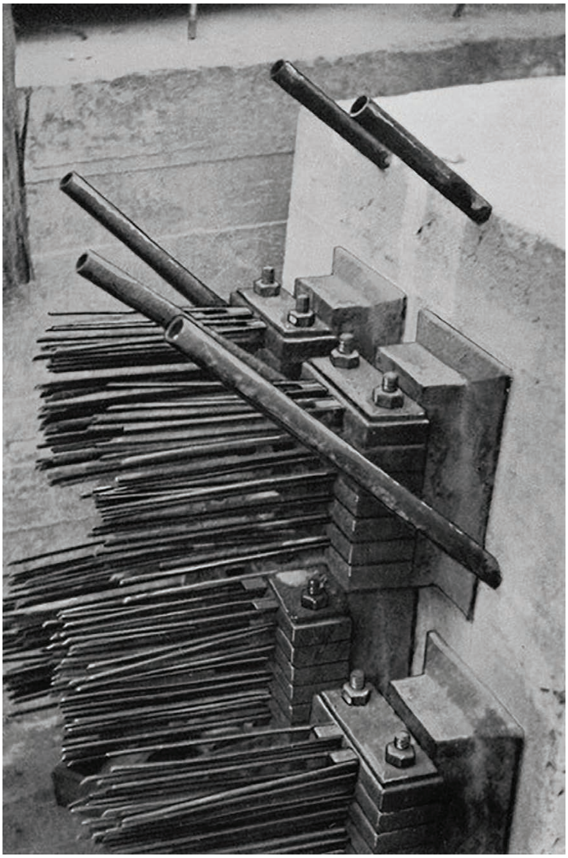

Figure 2.2.6 Blaton–Magnel Sandwich anchorages for 5-mm steel wires, used here for the very first time for the 1943 test beam on the construction site at rue du Miroir (Brussels).

Source: Blaton Archive, Fondation CIVA.

force on concrete as with the 5-mm wires used until then with relatively similar dimensions. The Sandwich system of post-tensioning remained in use – particularly in Belgium – until the 1960s. But the company did not make the technological transition to the use of seven-wire strands.

Civil Engineering, Infrastructure and Bridges

The company Ciments & Bétons led by Armand J. Blaton, whose reputation was already well established, obtained its first large civil engineering project with the construction of a part of the vaulting of the capricious Maelbeek stream in the years 1894–1895. This project, conceived under the direction of engineer Jules Zone (1860–1942), head of the technical studies office of the province of Brabant since 1892, planned to collect the frequent and devastating flooding of this watercourse, which flowed through the Brussels municipalities of Ixelles, Brussels, Saint Josse and Schaerbeek, in a vaulted sewer over several kilometres. It involved the construction of unreinforced concrete structures where the collector had either a circular shape of 4.5 m diameter, or a section covered by a 60-cm-thick low arch, with an opening of 9 m and a rise of 1.35 m (Figure 2.2.7).

In 1892, Jules Zone became a very active member of the Belgian Society of Engineers and Industrialists (created in 1885), of which Armand and Jules Blaton were also members. Jules Zone was a firm promoter from 1889 of the creation of a port in Brussels, connected to the sea by the Willebroeck Canal, which was to be enlarged in size and depth. Jules Zone became deputy director of the Société du Canal et des Installations Maritimes de Bruxelles created in 1895, and in 1900 Armand J. Blaton won the contract for the Société du Canal to build the port of Brussels and the first section of the Willebroeck Canal to be widened and deepened, that is about 3.5 km of work of such a magnitude that Ciments & Bétons was associated with the contractors Désiré Declercq from Roeselare and Georges Lapierre from Ypres (Provost 2017: 157). In 1903, the same association of contractors was awarded the contract for the work on the second section of the Maritime Canal, bringing the total length of the port and canal facilities built by the same association to 17 km (Figure 2.2.8).

This was followed by a long series of bridge constructions for the Belgian State Railways by the company of Armand Blaton.

The first was the construction in 1905 of five reinforced concrete bridges over the railway tracks in the district of Laeken (Brussels) based on a project designed by the company itself.

Figure 2.2.7 Construction of the canal tunnel collecting the Maelbeek stream in Schaerbeek, 1894–1895. Note the unreinforced 90-cm-thick concrete vaulted roof of the sewer and the driving of timber piles.

Source: Blaton Archive, Fondation CIVA.

Figure 2.2.8 Construction of the first section of the Maritime Canal (photograph dated 17 July 1901).

Source: Blaton Archive, Fondation CIVA.

In 1905, Blaton also built the Teichman viaduct over the railway tracks at Schaerbeek station (Figure 2.2.9): most of these bridges were of the continuous beam type, and this viaduct is perhaps the very first of this type to be built in Belgium, in the same year in which Hennebique built the Mativa footbridge in Liège.

But the company did not only build in “agglomerated” or reinforced concrete. In 1906, Blaton raised the tracks of the Aalst station to cross the Dender river. The river pier was founded with compressed air caissons, and the approach spans were built in masonry (Provost 2017: 160). This was work done to modernize the Brussels–Ghent railway line 50, undertaken in view of the Ghent World Fair in 1913.

In the 1920s, the Armand Blaton company built several arch bridges in masonry or concrete for the works of the new railway line 50A, doubling line 50 between Brussels and Ghent. But the most spectacular of the bridges undertaken by Blaton in those years is the construction between 1921 and 1924 of a large viaduct allowing the line 126 to cross the Meuse at Huy (Figure 2.2.10). This bridge was constructed of three large arches built in stone masonry according to the great French tradition brought to its peak by the engineer Paul Séjourné (1851–1939), following the designs of the chief design engineer of the railways, Raoul Desprets (1884–1963). With their 46.8-m opening, they are probably the largest stone masonry arches ever built for a bridge in Belgium. The bridge was partially destroyed on 12 May 1940 by the Belgian army, but rebuilt in 1941 by Blaton-Aubert, this time using concrete. While that bridge still exists, line 126 was gradually decommissioned between 1965 and 1975.

Figure 2.2.9 The Teichman reinforced concrete road bridge built by Armand Blaton over railway lines in Schaerbeek in 1905.

Source: Blaton Archive, Fondation CIVA.

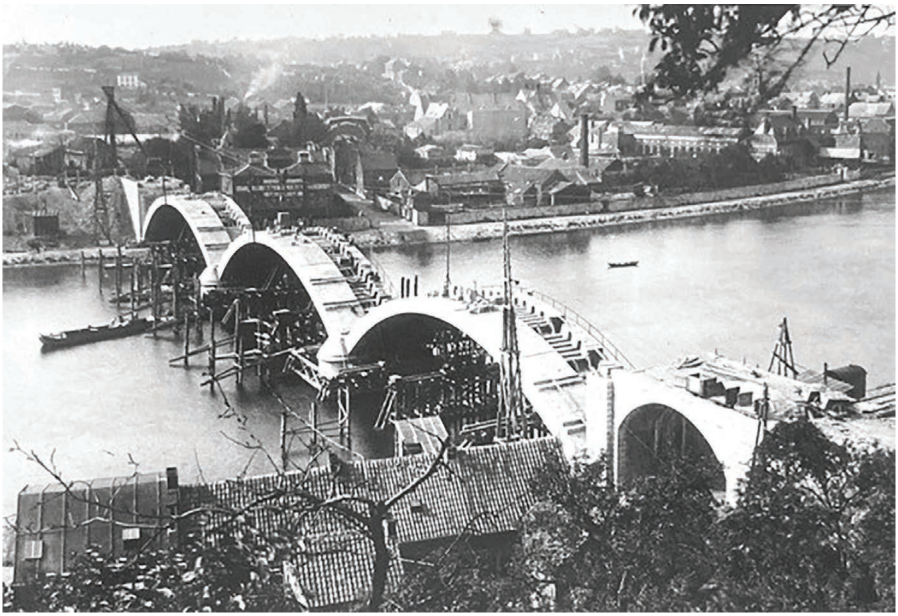

Figure 2.2.10 Construction of the railway bridge over the Meuse at Huy, 1921–1924.

Source: Blaton Archive, Fondation CIVA.

A very important civil engineering work in Brussels, although largely unknown, is the 1,716-m-long Cinquantenaire railway tunnel, located in the communes of Etterbeek and Schaerbeek. It is the main structure of railway line 26. A first section of 195 m was built in the open air in 1896. A first underground construction site began in 1910 while the surface lots were not yet built, but the works were abandoned after 18 months of testing several techniques. At that time, 228 m of tunnel had been executed on the Schaerbeek side and 53 m on the Etterbeek side. A dozen years later, the surface land was largely built up, and 1,240 m of tunnel remained to be built underground in very difficult soil conditions. Armand Blaton joined forces for the 1924 tender with the company Maison Fougerolles Frères from Paris, which had good experience in the construction of underground tunnels. The work was carried out from October 1924 to April 1926: the company, which was free to choose the method of execution, used a method with a very fractioned section by which the entire lining of the tunnel – except for the invert – was carried out by the digging and concreting of armoured galleries (Provost 2017: 186–190).

In the 1930s, which were years of economic crisis, Blaton did not seem to carry out any major civil engineering works or works resulting from public tenders: in particular, it was absent from the construction of the Albert Canal and its engineering structures. The creation of an underground rail link through Brussels between the North and South stations started in 1911, was relaunched in 1936 and was only completed in 1952. Here, too, the Blaton company was barely involved in the realization of this important infrastructure, except for the construction of concrete slab bridges at the two open ends of the junction, and in particular for the execution, from 1942 onwards, of the rail bridge decks over the rue du Miroir (now rue Roger van der Weyden), where a prestressed concrete beam was tested up to failure for the very first time in Belgium in 1943, and later the construction of a prestressed concrete slab deck (Figure 2.2.11) (Espion 2015).

Between 1944 and 1954, Blaton's main contribution to civil engineering works was the reconstruction of bridges destroyed by the war with his prestressed concrete technique. Particularly noteworthy is the reconstruction in 1949 of the Sclayn Bridge over the Meuse with a two-span continuous girder bridge in prestressed concrete, which was a world first (Espion & May 2020).

Industrial Constructions

Industrial construction had been an important part of Blaton's activity since the advent of reinforced concrete. In the archive, there are countless projects for the construction of silos, water towers, industrial halls, workshops, locomotive depots, gas plants, power plants, garages, breweries, cement plants and so on. Industrial construction projects certainly receive less attention – and are less glamorous – than completed bridge projects, which are often described in engineering magazines, or completed apartment buildings or offices, commonly reported in architectural magazines.

But industrial construction is special in that the company usually obtains the contract for a construction either directly from the client or following a very limited tender. So, it is important for the contractor to satisfy the industrial clientele – and there are several cases in the archive that show that an industrial company repeatedly opted for Blaton as a contractor, over a long period of time, even. For example, there are files in the archive concerning the construction of workshops for the Ateliers de Constructions Électriques de Charleroi (ACEC), from 1909 (Figure 2.2.12) to 1953 (Figure 2.2.14).

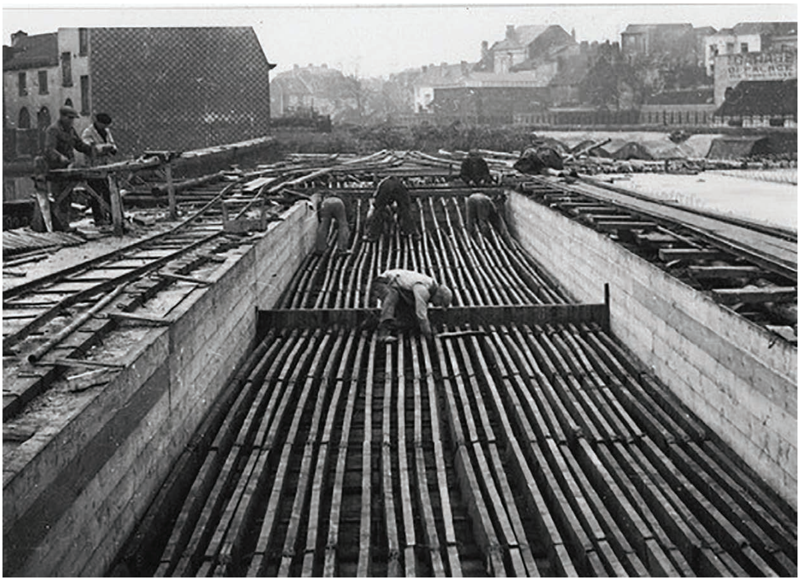

Figure 2.2.11 Laying the Sandwich cables for the railway bridge deck over the rue du Miroir (Brussels) in 1943 (or 1944).

Source: Blaton Archive, Fondation CIVA.

Figure 2.2.12 Factories and workshops for the Ateliers de Constructions Électriques de Charleroi in 1909.

Source: Blaton Archive, Fondation CIVA.

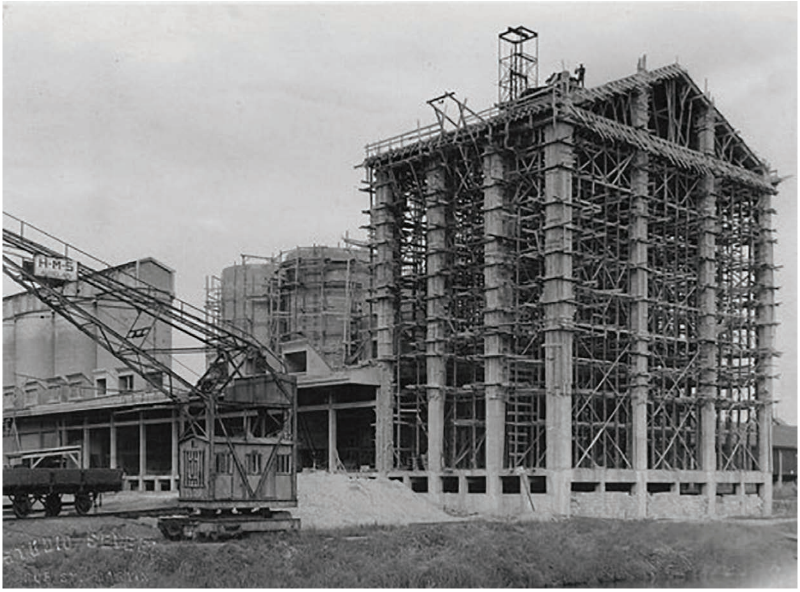

Figure 2.2.13 Construction of the extensions of the Dapsens cement factory in Vaux (Tournai) in 1943.

Source: Photograph by Studio Severin, Blaton Archive, Fondation CIVA.

Figure 2.2.14 New workshops for the electronics division of the Ateliers de Constructions Électriques de Charleroi in 1953.

Source: FEBELCEM Archives.

Another example is the case of the Dapsens Cement Works in Tournai in the 1920s and in 1943 (Figure 2.2.13). In Figure 2.2.13, the four silos on the left were built in reinforced concrete by Armand Blaton in the 1920s, and the four silos on the right, as well as the cement bagging building, were built in 1943 by Blaton-Aubert. It is worth noting that this construction gave Blaton and Magnel the opportunity to implement two world-first applications of prestressed concrete technology (Espion 2015). This application of prestressed concrete during the German occupation of Belgium provides striking proof of the merits of the technique in terms of speed of execution and economy of construction materials (Espion & Hellebois 2017: 83–85; Espion & May 2020).

According to what is known about the activities of Blaton before 1905, reinforced concrete was first used for industrial constructions before it was used for buildings. Baes (1932: 648) cites about ten industrial constructions in reinforced concrete already built by Armand Blaton between 1897 and 1900. The photographic albums in the archive show the development of important industrial constructions before 1914, such as the construction of a gas factory in Jette in 1908–1913 (Espion & Hellebois 2017: 94), warehouses for the Delhaize stores in 1912 (Espion & Hellebois 2017: 71) and the beginning of the construction on a large locomotive depot in Schaerbeek in 1911, which was only completed in 1920 (Espion & Hellebois 2017: 210).

After the First World War, Blaton's industrial construction activity took off considerably, especially where fire safety and speed of construction through prefabrication were crucial. In the years 1920–1930, the company built industrial sites of various sizes all over Belgium, especially for breweries, metallurgical companies, paper mills, grain and cement warehouses and the refrigeration industry. During this period, Blaton's clients became concerned with the image of their industrial activity, and collaboration with architects grew increasingly important. In this respect, the constructions realized by Blaton as early as 1924 for the booming automotive industry – garages, showrooms or production plants – are exemplary (Devos 2017a: 130–133).

Blaton-Aubert was applying the prestressed concrete technique to the construction of industrial buildings to create floors in multi-story buildings or roofs as early as 1945. Essentially, this involved prefabricated "beam" type elements prestressed by the Sandwich cable. Prestressed concrete could be used to create beams that are much slenderer than those rendered in reinforced concrete, thus increasing the span of the beams for a given depth, and the structural typology of roofs with reinforced concrete arches or vaults, which was previously used to cover industrial halls, was replaced by prestressed concrete beam grids. The most extensive example of this type of construction by Blaton is the factory of the Union Cotonnière (UCO) in Ghent in 1948 (Figure 1.6.11, see Chapter 6), which was widely described in the literature of the time and whose construction site received many visits, even from abroad. It should be noted that the Blaton's design office often implemented this type of structure with "external" prestressing (Figures 2.2.14 and 2.2.20).

Building with Architects

There are many clues and files in the archive, which allow us to analyse the relations between Blaton and the architects involved in the construction of buildings. This collaboration could take different forms:

- the company might enter into contact with an architect, following a request for a quote from the latter or from a client; this explains the presence in the archive of many files (containing architectural plans) that were not followed up with the project actually being carried out, for whatever reason;

- the company, acting as a real estate promoter, directly commissioned an architect; this did not happen, however, until the end of the 1920s, when the company Industra was created and when the brothers Armand E. Blaton and Émile Blaton in 1930 set up the real estate company Union mobilière et Immobilière.

Its directors were thus in contact with many architects, including the most renowned in Belgium at the time, and representing all architectural styles. The company mainly erected buildings in Brussels and Antwerp.

As a reminder, the archive is not very rich in files concerning the constructions realized before the First World War: for this period, it is necessary to refer to the photographic albums to estimate which works by the company were considered significant enough and deserving to be kept in an album. This excludes a lot of minor works carried out for private clients.

Before 1914, the albums reveal only three significant buildings, all in the eclectic (Beaux-Arts) style:

- in 1903, the offices of the Compagnie Générale des Tramways d'Anvers, with the architect Jean-Laurent Hasse (1849–1925);
- in 1909, the department stores Galeries Nationales in Brussels, with the architects J. Dosveld and Ch. Petein;
- in 1912–13, an extension of the Caisse Générale d'Épargne et de Retraite bank with the architect Alban Chambon (1847–1928).

All these buildings still exist today (2022). The absence of plans makes it impossible to appreciate the importance of reinforced concrete in these constructions, but it is unlikely that it was used for anything other than foundations and floors, given that at that time in Belgium, the reinforced concrete beam–column structure was reserved for industrial applications.

The apex of Armand J. Blaton's career as a contractor was his collaboration with architect Victor Horta (1861–1947) on the construction of the Palais des Beaux-Arts in Brussels (1923–1928), a particularly complex construction which included a large concert hall and exhibition spaces (Figure 2.2.15) (Devos 2017a, 2017b). Horta considered Armand Blaton *a priori* as a contractor for the Belgian State Railways, but at the end of the construction of the Palais des Beaux-Arts, he was pleased with his collaboration with the latter.

In 1927, the brothers Armand E. and Émile Blaton took over the company, immediately giving it a fresh boost by engaging in the construction of apartment buildings and offices.

The construction of apartment buildings for the middle or upper class was facilitated in Belgium by two factors (Devos 2017a):

- the entry into force of the 1924 law on co-ownership;
- the doubling of construction prices between 1914 and 1920.

In the years 1928–1929, Industra built for Léon Roersch one of the first large-scale apartment buildings, on the basis of design of Paul Riquet (1876–1956) for an art deco building on Brugmann Square in Ixelles (Brussels). At the same time (from 1928), Industra also created an apartment building with the architect Maurice Van Isacker on Victor Hugo Street in Schaerbeek, also in Brussels.

One area of Brussels where Blaton was very involved in several projects – some of which never came to fruition – is the space between rue Ravenstein and rue Cantersteen, or between

Figure 2.2.15 The Palais des Beaux-Arts at the corner of the rue de la Bibliothèque and the rue Ravenstein, Brussels, around 1928. Architect, Victor Horta.

Source: Archives: Fonds Palais des Beaux-Arts (1928–2001), Brussels, © Archives Centre for Arts, Brussels and Graphopresse.

the Palais des Beaux-Arts and the (future) Central Station (Devos 2017a). Finally, Blaton built two remarkable office buildings in this block in art deco style by the architects Alexis Dumont (1877–1962) and Marcel Van Goethem (1900–1960): the Shell building (1931–1934) (Figure 2.2.16) and, adjacent to it, the offices of the Assurances Générales de Trieste (1934–1935).

In Antwerp, the Compagnie Anversoise de Travaux, a local subsidiary of Blaton, built:

- in 1933–1935, with the modernist architect Nachman Kaplansky (1904–?1956), a building to house 12 apartments in the Carnotstraat for the account of J. Maisel (Devos 2017a);
- in 1934–1936, with the architects Jean-Jules Eggericx (1884–1963) and Jos Somers (1899–1958), a modernist building for 21 apartments at the Frankrijklei for the account of the Union mobilière et immobilière, that is Blaton.

In 1937, the Société Belge de Constructions d’Habitations (SOBECO) built the Résidence Léopold at the Square De Meeûs in Brussels. The 14-storey building is one half of an impressive modernist ensemble of two twin buildings designed by the architects Jean-Jules Eggericx and Raphaël Verwilghen (1885–1963). Together, these two buildings frame the perspective towards the station in the Léopold district. At 55 m tall, the Résidence Léopold is one of the first of Brussels’s high-rise construction projects, considered in Belgium to be an “American formula”. In 1939, Blaton took over the project of building the second tower, the Résidence Albert (Figure 2.2.17), which was converted from an apartment building into an office building (Devos & Van de Maele 2017: 141).

Figure 2.2.16 The Shell building under construction at the corner of the rue Ravenstein and the rue Cantersteen, Brussels, around 1932. Architects, Alexis Dumont and Marcel Van Goethem.

Source: Blaton Archive, Fondation CIVA.

Figure 2.2.17 The Résidence Albert at the corner of the rue du Luxembourg and Square De Meeûs, Brussels. Architects, Jean-Jules Eggericx and Raphael Verwilghen.

Source: Blaton Archive, Fondation CIVA.

Blaton Goes International

Before 1890, the Blaton-Aubert company was present at various horticultural, industrial, and international exhibitions in Cologne (1875), Amsterdam (1877) and Paris (1878, 1889) to promote its prefabricated concrete products and concrete rockworks. However, Blaton did not carry out any construction work outside Belgium until 1930, when Armand and Émile Blaton founded a French subsidiary Études & Travaux with headquarters in Lille. The origins of the company are unknown, but from its creation, it worked on a vast industrial complex in Dunkirk: the installations of the oil refinery Les Pétroles du Nord. The descriptive brochure of these works indicates an abundant use of Vibro piles and large civil engineering and building works (Figure 2.2.18). It should be noted that the owner of this refinery was the Belgian group Compagnie Financière Belge des Pétroles (Petrofina, created in Antwerp in 1920), which could explain the reason for the creation of a French subsidiary by the Blaton brothers, as the construction market in France has always been very protectionist towards the arrival of foreign competitors. Apart from the works in Dunkirk, the activity of the company Études & Travaux in France before the war seems to be rather limited: some harbour works in Douarnenez and Brest, construction of some schools, participation with Blaton-Aubert in the construction of the Belgian pavilion at the 1937 International Exhibition in Paris. The refinery of Pétroles du Nord was destroyed during the Second World War.

From 1945, Blaton-Aubert promoted the use of the Sandwich prestressing system abroad, but this was done through a system of licensees of the process in each country. Sometimes, the studies were partly carried out by the design office of Blaton-Aubert in Brussels or by a specialized Belgian consulting engineer. Before 1949, the Sandwich system was used in the Netherlands by the company Betonbouw Dura for three building sites in Heerlen and by the company Dura's

Figure 2.2.18 Aerial view of the Pétroles du Nord oil refinery in Dunkirk.

Source: Photograph from Études & Travaux advertisement brochure, Blaton Archive, Fondation CIVA.

Aannemingsmaatschappij on four sites in Rotterdam. It should be noted that the Dutch company Dura was also a very old family construction company, founded in 1855. The Sandwich system was also well represented in Great Britain, with 13 applications before 1949, some of them quite spectacular. But the best-known application of the Sandwich system outside Belgium, and certainly the most important for its enduring influence in the international history of prestressed concrete, is its use for the girders of the very first prestressed concrete bridge built in the USA, the Walnut Lane [Memorial] Bridge over the Lincoln Drive in Philadelphia from 1949 to 1951 (Figure 2.2.19). The story of this project, in which Gustave Magnel played a decisive role on the construction site, personally leading a loading test up to failure of a 49-m span prestressed beam, has been told in detail by its promoter (Zollman 1978).

Blaton-Aubert also saw the Belgian Congo as a territory that promises a large diffusion of the prestressed concrete technique. At the end of 1949, the brothers Armand and Émile Blaton created the Compagnie Congolaise de Construction (CCC) with the financial support of the Lambert group. And the very first building to be constructed by the company was its headquarters in Léopoldville (Kinshasa), whose structure used prestressed concrete beams, with external prestressing (Figure 2.2.20). The building was completed in 1951, not without difficulty (Van Craenenbroeck 2015; Fivez 2018; Fivez 2019). A prefabrication subsidiary, Congobéton, was

Figure 2.2.19 The Walnut Lane Bridge over the Lincoln Drive in Philadelphia under construction.

Source: Photograph dated 9 July 1950, Blaton Archive, Fondation CIVA.

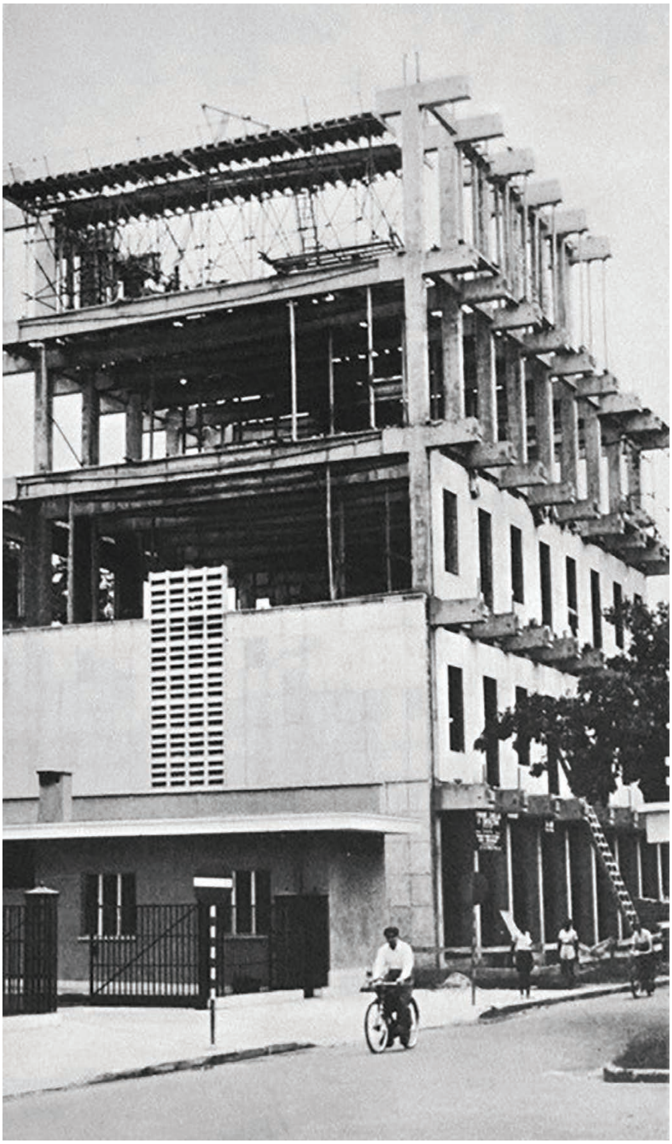

Figure 2.2.20 The headquarters building of the CCC under construction in Léopoldville (Kinshasa) in 1950.

Source: Photograph from an advertisement brochure by the CCC, Blaton Archive, Fondation CIVA.

created in 1951. Before the creation of the CCC, several construction companies of Belgian origin, subsidiaries of Belgian construction contractors or created at the instigation of Belgian financial groups, were already present in the colony: SOCOL (as of 1907), Safricas (1923), Trabeka (1924), Auxeltra-Béton (1947). The rather late creation of the CCC must therefore be understood in the perspective of the search for outlets for prestressed concrete, but this time by a subsidiary of Blaton and not by a licensee of its patents.

Conclusion

The family company Blaton accompanied the economic, industrial, architectural and urban development of Belgium from 1865 to 1954. This activity can be classified in three distinct periods, corresponding to three generations of leaders.

From 1865 to about 1890, the company Blaton-Aubert discovered and promoted the use of artificial cement, a new material for which it was necessary to find outlets. From 1876 onwards, it started prefabricating unreinforced concrete elements and carried out sanitation works in several large cities.

From 1895 onwards, Armand J. Blaton led the company towards civil engineering and infrastructure works and especially towards reinforced concrete construction as of 1897. His company built the first reinforced concrete bridges in Brussels (1905), as well as bridges and locomotive sheds for the railroads and many industrial constructions using reinforced concrete, with an area of activity that extended all over Belgium. It was only at the end of his career that Blaton used concrete for an important architectural project: the Palais des Beaux-Arts in Brussels under the direction of the architect Victor Horta.

From 1927 onwards, the third generation of managers led the company into diversification of activities with the creation of several companies:

- development of technological processes with Pieux Vibro in 1937 and prestressed concrete from 1942 (creation of the company Le Câble Sandwich in 1950);
- real estate development and construction of apartment buildings and office buildings in the 1930s, an activity that continued after the Second World War;
- international diversification with the creation of the French subsidiary Études & Travaux in Lille in 1930 and the Congolese subsidiary CCC in 1949.

In 1954, the final year examined by this investigation and before the division of the company, Blaton was one of the main Belgian contractors.

Notes

1 The names of the companies directed by members of the Blaton family have often changed over the period considered. For the sake of simplicity, we will sometimes use the generic name “Blaton” to designate any of these companies or the entrepreneurial family.

2 “Tout le Congo est un chantier. Re-assessing Congo’s architectural history from 1918 till 1975 through a construction history approach”, Doctoral research project by R. Fivez supervised by Professors J. Lagae (UGent), L. Taerwe (UGent) and R. Devos (ULB).

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Chapter 2.3

Rodolfo Stoelcker

A German Engineer-Contractor in Italy in the First Half of the 20th Century

Simonetta Ciranna

Introduction

Rodolfo Stoelcker arrived in Rome in October 1912, at the age of 32. Soon after, on 22 January 1913, an industrial patent for a "reinforced concrete pipe joint with internal pressure" with a duration of three years was registered in his name (Ministero di Agricoltura, Industria e Commercio 1915: 8). It was in October 1914, however, that he registered his own *Impresa per costruzioni d'ingegneria d'ogni genere, specialmente cemento armato, fondazioni, ponti, iniezioni di cemento, opere idrauliche, ecc*. (enterprise for engineering constructions of all kinds, especially reinforced concrete, foundations, bridges, cement injections, hydraulic works, etc.) with the Rome Chamber of Commerce.[1]

Originally from Ettenheim in Baden-Württemberg, Germany,[2] Stoelcker had already been in Italy since 1906, working in Genoa as an engineer for Wayss & Freytag of Neustadt an der Haardt (today Neustadt an der Weinstrasse),[3] an important company in Germany and owner since 1893 of the patent of Joseph Monier (1823–1906) filed in 1880, which helped transform Monier's ferro-cement into reinforced concrete thanks to the skill and continuous experimentation of its technicians.[4]

It was in Genoa that, in April 1908, Stoelcker and Swiss engineer Oscar Huber (1875–1945)[5] found themselves among the founders of the Società Ferrobeton Anonima Italiana sistema Wayss & Freytag,[6] a subsidiary that aimed to strengthen the presence in Italy of the aforementioned German company after the Ministry of Public Works had issued the first regulations dedicated to the execution of public works in reinforced concrete in January 1907 (Ministero dei Lavori Publici 1907).[7]

Thus, it was within the framework of Wayss & Freytag (Figure 2.3.1) that Stoelcker acquired a solid professional competence and experimental capacity, favoured also by his acquaintance and relations with Emil Mörsch (1872–1950), who, from 1901, was the technical director of the aforementioned company as well as professor of Reinforced Concrete Construction at the Eidgenössische Technische Hochschule (ETH) in Zurich and the University of Stuttgart and one of the founders of the theory of reinforced concrete construction.[8] Stoelcker's theoretical knowledge and interests in applied research are also endorsed by two articles he published in 1906 focusing on the calculation of reinforced concrete plates and the differences with those without reinforcement (Stölcker 1906a, 1906b).

As an employee of Wayss & Freytag, in 1907–1908, Stoelcker and Huber oversaw the construction of two reinforced concrete bridges to be built with the systems patented by company, one over the Padrongianus stream and the other over the Posada River in the province of Sassari. However, after having "prepared, founded and directed the Ferrobeton company until the

DOI: 10.1201/9781003368656-13

Figure 2.3.1 Ferrobeton advertisements from 1909 (top) and 1912 (bottom). Top: only the city of Genoa is indicated as the location of the company's head office. Bottom: Milan, Rome, Naples and Messina also appear, and the capital is indicated as the office of the international company.

Source: Annuario genovese. Guida Amministrativa, Commerciale e Industriale di Genova, Provincia e Liguria, 1909 and 1919.

autumn of 1912, designing and executing many engineering works, mainly in reinforced concrete, in every region of Italy, from Sardinia to Dalmatia, from Sicily to Piedmont", Stoelcker left this company "because of irremediable political disagreement with the German capitalists", and began to work independently from 1913.[9]

However, the restart of his activity in Rome was hindered precisely by his German origins. These were the years that heralded Italy's entry into the First World War, and Stoelcker faced first hostility and later being forbidden to practise in the first person. That happened soon after he gained his first important assignment in Rome, that of building the Simplex pile foundations for the Ministry of the Navy, and during the course of construction he was obliged to appoint his brother-in-law as the company's contact person.[10] Nevertheless, the construction site documents for this imposing building designed by the architect Giulio Magni (1859–1930) on the Lungotevere delle Navi highlight Stoelcker's central role in the management of an innovative foundation system, Simplex piles.[11] In this work (Figures 2.3.2 and 2.3.3), the execution of the piles became gradually more difficult due to the discovery of numerous archaeological remains in the subsoil, which led to the breaking of the piles. Added to this problem were other factors that heavily conditioned the works: the scarcity of metal materials (e.g. cast-iron spikes for the piles), delayed deliveries (of iron as well as of pile drivers from Germany) and the shortage of skilled labour called up to war and sent to the front.

To enable the use of the Simplex pile foundation system and the execution of hydraulic works, Stoelcker invested in the acquisition of the necessary equipment (e.g. pile drivers) and created a specialized competence that allowed him to participate and often prevail – as in the Ministry of the Navy – in numerous tenders, in which he competed with leading Italian and international companies in the field of reinforced concrete construction.

Bridges

The use of patents and technologies linked to Germany and, in a broader sense, to the most advanced research on the use of reinforced concrete on an international scale is also evidenced in Stoelcker's involvement in the construction of the Tazio Bridge in Rome, built over the Aniene River to connect via Nomentana with the new Montesacro district, on a project from 1920 carried out by the company Filippo Zanetti under the guidance of architect Gustavo Giovannoni (1874–1947) (Benedetti 2012). In 1923, Stoelcker was commissioned to consolidate the foundations of the abutment and abutment-pile, which had been inadequately built on sagging ground, and set up a slab-on-grade foundation with piles patented by August Wolfshotz Preszzementbau.[12]

Stoelcker's involvement in this work continued in 1938–1939 with a total reconstruction of the central arch of that bridge (Figure 2.3.4), which led to the replacement of the existing unreinforced concrete arch with a three-hinged reinforced concrete arch, with a higher profile and lower horizontal thrust at the abutments.

Finally, in November 1944, Stoelcker, by then an Italian citizen since 1923, was asked as the original designer of that bridge to direct the works needed to repair the damage caused by the sabotage of the German troops who dynamited it in their retreat from Rome.[13]

The construction of bridges, of different scales, functions, relevance (urban, territorial and "political") is, indeed, a constant in the 50 or so years of Stoelcker's Italian activity. In this field, the repeated involvement in bridge construction, such as the Tazio or Nomentana bridges even after the WWII, exemplifies Stoelcker's professional solidity and "resilience" to changing political regimes.

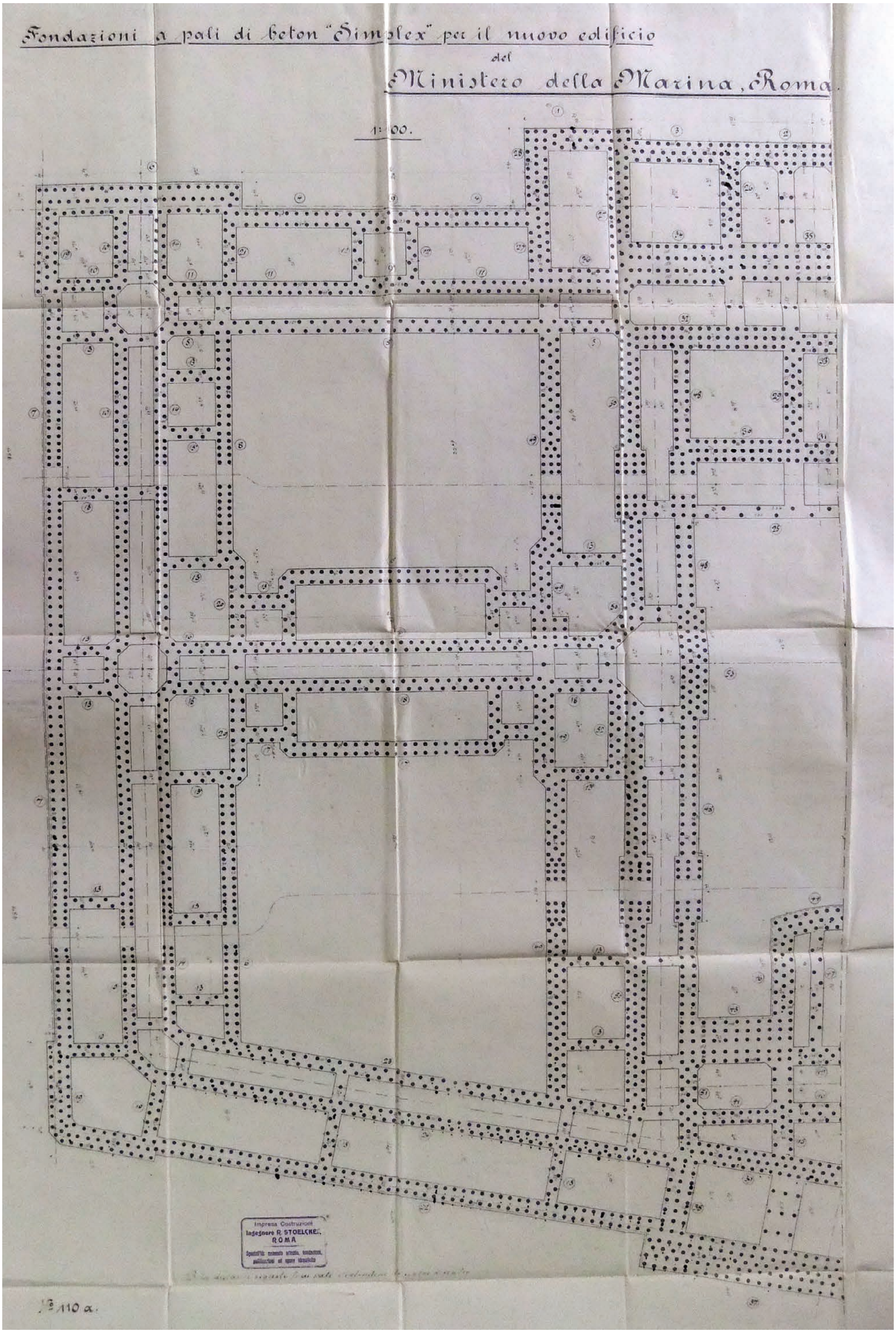

Figure 2.3.2 Rome, Ministry of the Navy, planimetry of the foundations with Simplex concrete piles on a scale of 1:100 representing half of the building.

Source: State Archives of Rome, Roman Civil Engineering Office, file no. 915.

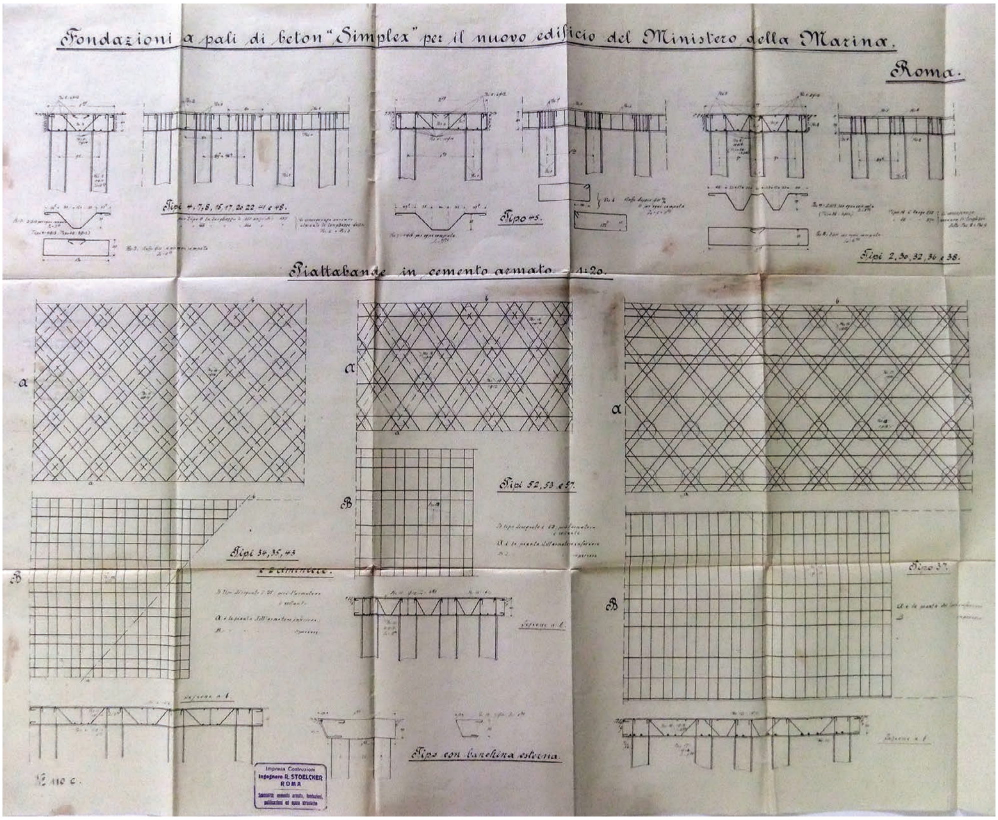

Figure 2.3.3 Rome, Ministry of the Navy, Simplex concrete piles; details related to the reinforced bars.

Source: State Archives of Rome, Roman Civil Engineering Office, file no. 915.

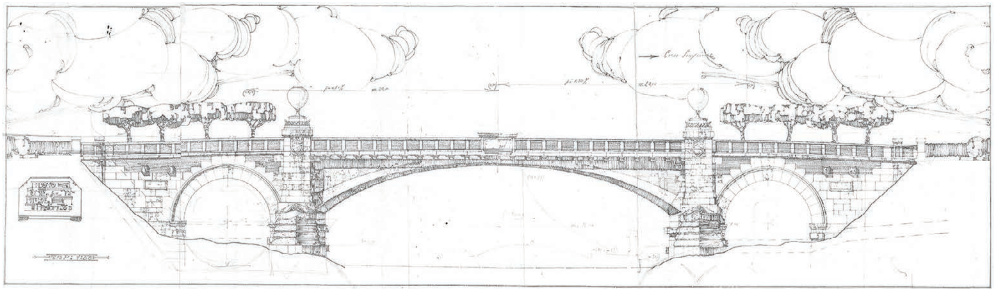

Figure 2.3.4 Ponte Nomentano, Rome, upstream elevation, 1938.

Source: Rome, *Dipartimento Sviluppo Infrastrutture e Manutenzione Urbana*, *Ufficio Ponti*, Ponte Tazio.

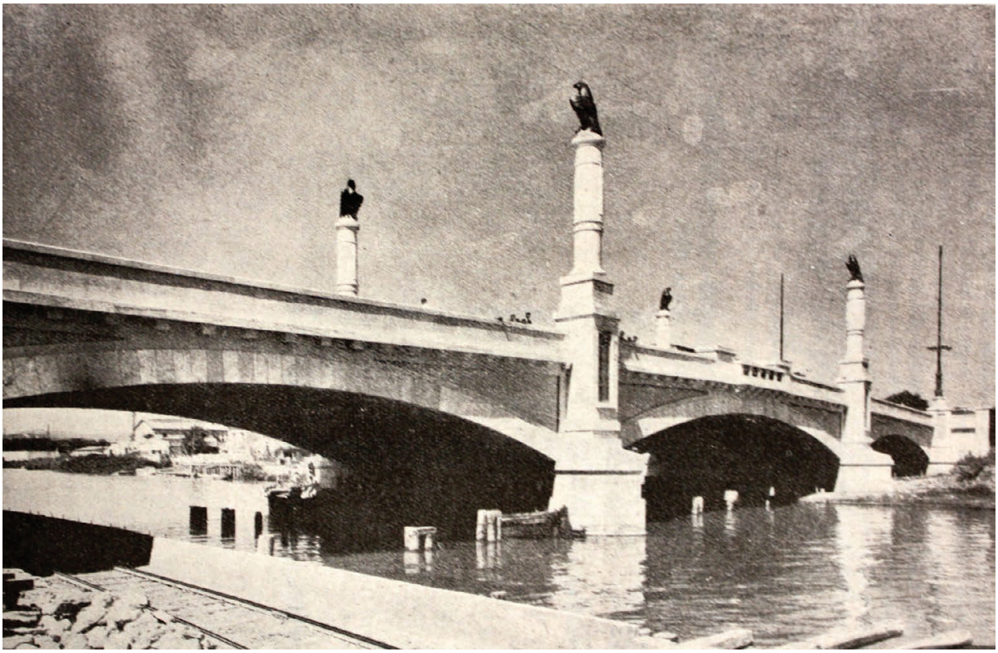

Figure 2.3.5 Pescara, Ponte Littorio over the river Pescara: photo just after work was completed.

Source: Fago (1935).

These contexts and changes led him to respond to different needs, as well as to deal with designers whose own training and language combinations produced heterogeneous results, some of which, moreover, were wiped out by the wartime destruction of the Second World War.

The latter include the bridge over the Aventino river in the municipality of Casoli (Chieti, Abruzzo) built between 1923 and 1925 and destroyed in 1943[14]; the bridge over the via Appia in Minturno (Latina, Lazio) built in 1927, destroyed by the Gustav Line bombing in 1944 and rebuilt two years later[15]; and the imposing Ponte Littorio bridge over the Pescara River built between 1930 and 1933, destroyed in 1944 and rebuilt after the war under the new name of Ponte Risorgimento (Figure 2.3.5).

Much more than its predecessors, the last of these bridges had a strong monumental vocation, connecting the two municipalities of Castellammare Adriatico and Pescara, which since January 1927, at the proposal of Benito Mussolini – encouraged by the Pescara poet Gabriele d'Annunzio (1863–1938), among others – had been merged in the single municipality of Pescara.

To emphasize this territorial and administrative change, the Ministry of Public Works called on the Roman architect Cesare Bazzani (1873–1939), who was inclined to a courtly classicism pleasing to the Fascist regime, to design it. Structurally, the bridge consisted of seven continuous longitudinal beams on four piers with varying moments of inertia, with a load-bearing structure made of reinforced concrete made of high-strength 350-kg cement. All the structural elements, such as piers, abutments, *armillae* and cornices, were clad in Ascoli travertine, while the decorative parts such as parapets, lictor columns, plinths and balconies were in Trani limestone and the kerbs of the pavements in Sardinian granite (Figure 2.3.6). The gables of the arches and the

Figure 2.3.6 Invitation to the inauguration ceremony of the Ponte Littorio by the *Podestà* printed by Nicola D'Arcangelo's typography.

Source: Millevolte (2019: 47).

intrados were executed with cement mortar plaster imitating travertine.[16] The lightness of the stones used was then enhanced with the decorative elements of the bronze eagles by sculptor Renato Brozzi (1885–1963) and the two statues by sculptor Nicola d'Antino (1880–1966) were installed during the summer of 1935.[17]

Documenting the company's range of action in the construction of bridges are Stoelcker's works in 1930: in October, alongside the Directorate of the Road Service of the Municipality of Rome, the widening of the Salario Bridge in Rome,[18] and in November the executive project for the bridge over the Greve stream in the locality of Casellina for the variant of the state road 67 Florence-Ponte Elsa, under a concession delivered by the Azienda Autonoma Statale della Strada.[19]

In the early 1930s, Stoelcker's interests in Tuscany are attested by the opening of one firm branch in Florence, located in via Calimala in the city centre, which was mentioned several times in local bulletins and yearbooks.[20] Remaining on the subject of bridges, in August 1933 Stoelcker takes also part in the call for tenders issued by the municipality of Prato for the construction of a reinforced concrete footbridge over the Bisenzio river, linking via S. Antonio with via XXIII Marzo. In the tender won by Ferrobeton of Rome, among other companies, the Roman company Nervi & Bartoli (Guanci 2008: 183–195)[21] participated with an elegant architectural static solution.

Among the documents enclosed with his application for this tender, Stoelcker included two portfolio lists, one relating to works that his company was in the process of completing on

1 October 1932 and the other to those already completed on that date. Limited to reinforced concrete bridges, in the first inventory he listed, in addition to the monumental bridge over the Pescara River,[22] other bridges over the Bisenzio for the Ministry of Public Works, 15 "small bridges" in various locations in the Piscinara Reclamation Area for the *Consortio* and the bridge over the Bruna in Gavorrano (Grosseto, Tuscany). In the second list, he included bridges in Casoli (Chieti, Abruzzo), Arli (Ascoli Piceno, Marche), Amatrice (L'Aquila, Abruzzo) and in Cittaducale (Rieti, Lazio) for public administrations; in the Maremma Toscana for the Genio Civile and the Province of Grosseto; over the Garigliano and the Alveo della Piana canal for the Genio Civile of Caserta; in the Padule di Fucecchio (Florence, Tuscany) for the Ministry of Public Works; on the Brizzi near Sapri for the Caserta Public Works Superintendency; on the Elsa river near Marsiliana for the Azienda Autonoma Statale della Strada, as well as the repair of a number of bridges on the via del Mare (Rome-Ostia motorway), and the aforementioned work to widen the Salario bridge over the Aniene for the Province of Rome and the bridge over the Greve.

This significant activity continued over the years with at least three other major bridges built, the first in Rome under a contract of 1939 and the other two in Abruzzo during the years of post-war reconstruction, one in the municipality of Salle between 1949 and 1951 and the other in the municipality of Aprati between 1952 and 1953. In fact, even during the brief interlude brought about by the bankruptcy of the company, declared in 1935 and concluded with the approval of a composition with creditors in May 1937,[23] Stoelcker had consent to continue the construction of the Casilino flyover road in Rome over the State railway tracks at via Gallarate and via Aquila, the contract for which had already been signed with the Province in December 1933.[24] The contract for the construction of the new bridge over the Tiber at San Giovanni dei Fiorentini dates back to November 1939, following a call for tenders dated from 28 April of the same year. The bridge was to be built at the mouth of the new tunnel under the Janiculum Hill between the Ponte Vittorio Emanuele bridge and the Ponte Sospeso.[25] The latter, known as the "de fero" (iron) bridge, was one of the four suspension bridges entrusted by the Reverenda Camera Apostolica to the Società dei Ponti in Ferro in the 1840s[26]; Stoelcker was also entrusted with its demolition, undertaking to re-use the resulting materials. Named after Prince Amedeo di Savoia Duke of Aosta (1898–1942), the new bridge was built between 1941 and 1942 with a design by architect Giuseppe Bronzetti (1904–1944).[27] It had three arches in brickwork, piers of masonry and travertine on compressed air foundations and abutments consisting of the retaining walls "adapted and reinforced with piling and cement concrete blocks" (Figure 2.3.7).[28]

In the same period, in 1943, the Government of Rome also commissioned Stoelcker with the special maintenance works of the Ponte del Risorgimento inaugurated in May 1911 on the occasion of the 50th anniversary of the Unità Nazionale. Known for the boldness of its single span, a low arch with a span of 100 m and 10 m rise, this bridge was the first to be built in reinforced concrete in Rome, by the company of engineer Giovanni Antonio Porcheddu (1860–1937), the only concessionaire in Italy of the François Hennebique (1842–1921) patent. Regarding the subject of the contract awarded to Stoelcker, the maintenance work specified "the repair of damage in the walls of the longitudinal diaphragms and abutments of the bridge by means of pressure injections".[29]

If the design and execution of the Principe Amedeo di Savoia Aosta Bridge appear to be "autarkic" expressions of the Fascist regime, the two bridges built in Abruzzo in the early 1950s for the Cassa del Mezzogiorno (Grassini et al. 1962: 164–166) are quite different in terms of structural and architectural experimentalism. Among these, the bridge over the Orta River in the commune of Salle stands out for its formal and structural synthesis (Figure 2.3.8). It was

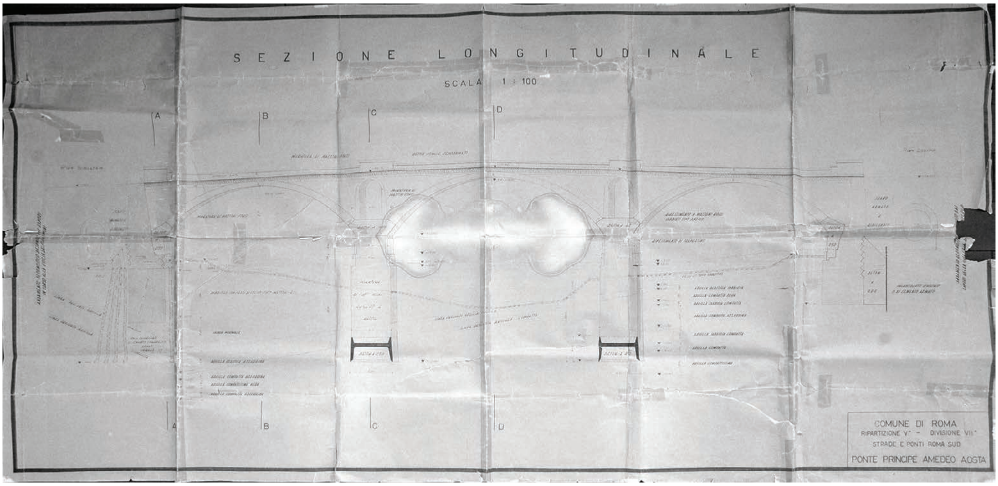

Figure 2.3.7 Ponte Principe Amedeo di Savoia Duca d'Aosta near San Giovanni dei Fiorentini, Rome.

Source: *Dipartimento Sviluppo Infrastrutture e Manutenzione Urbana-Centrale Unica Lavori Pubblici* (SIMU), folder no. 21 Fiorentini.

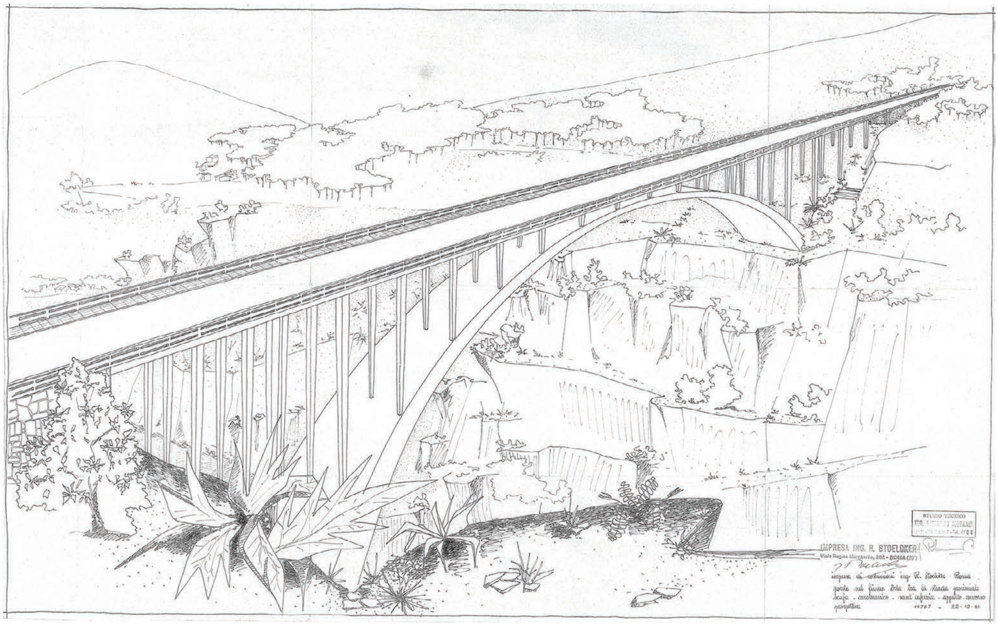

Figure 2.3.8 Salle, bridge over the Orta River, 22 December 1951, perspective of the project engineer Riccardo Morandi and engineer-contractor Rodolfo Stoelcker.

Source: Historical Archive Provincial Administration of Pescara, file no. 1, fasc. 1.

built between 1952 and 1955 by the Stoelcker company together with the engineer Riccardo Morandi (1902–1989), whose notoriety and design rigour in those years combined with decisive research, in particular, on prestressed reinforced concrete.

This work was the result of a long bureaucratic and planning process, which can exemplify the transformations in the field of engineering and the emergence of the use of reinforced concrete. Starting in 1926 with a design for a viaduct with several arches in rubble masonry lined with freestone, arches in concrete and frontal *armillae* in freestone, the final call for tenders in 1951 included the possibility of using prestressed reinforced concrete. The call for tenders was based on an outline project by the Technical Office of the Province of Pescara for a reinforced concrete bridge consisting of an interlocking arch completed with pilasters, located just upstream of the Orta outlet of the Arigastia stream. This work was done in a context of great landscape impact, having on the left a high, almost vertical rocky bank and, on the right, a spur jutting out towards the riverbed (Figure 2.3.9).

In the final solution, the bridge was executed with a single arch measuring 202.70 m in length, with a Ligowski's catenoid profile. Strassner's tables were used for the definition of the influence lines and drawn from the tapered downward profile (Ciranna 2019a: 37–42).[30]

The second bridge in Abruzzo was built between 1952 and 1953 in the Teramo area over the Vomano River, on the Cervaro-Aprati road (Figures 2.3.10 and 2.3.11). In this case, Stoelcker acted in the dual role of designer and contractor. The bridge, which is smaller in size and formally less "dynamic" than the previous one, is also located in an orographic and landscape context of particular beauty.[31]

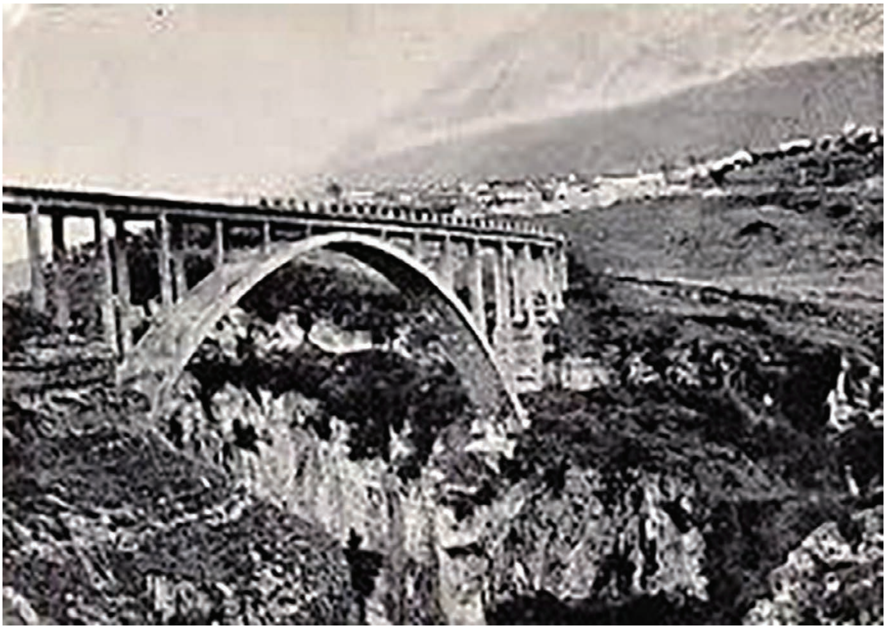

Figure 2.3.9 The Salle bridge over the Orta River in a period postcard.

Source: Ciranna (2019a).

Figure 2.3.10 Bridge over the Vomano River, 1952–1953 photo during construction.
Source: Uffici Amministrazione Provinciale di Teramo.

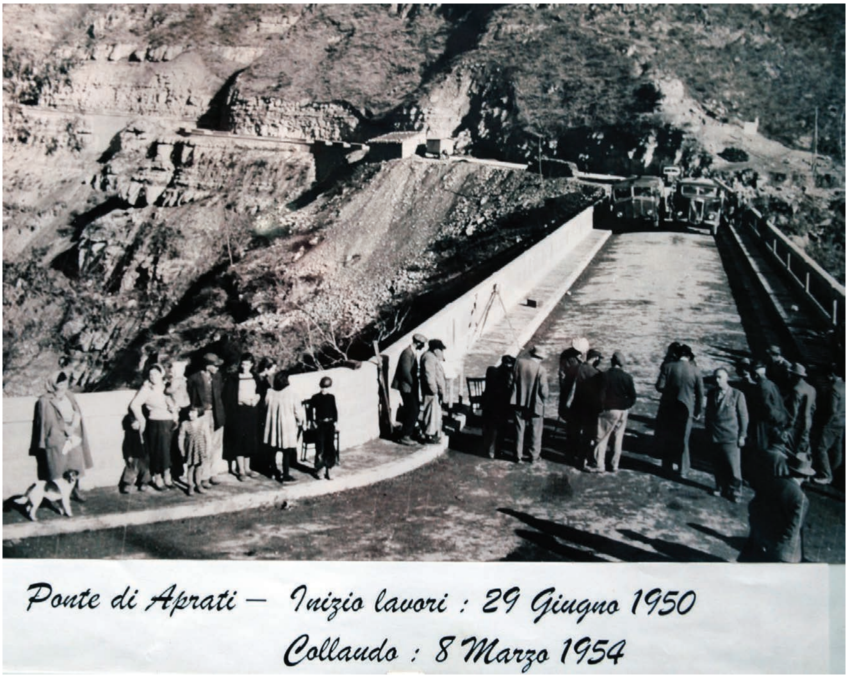

Figure 2.3.11 Bridge over the Vomano River, proof load test on 8 March 1954.
Source: Uffici Amministrazione Provinciale di Teramo.

Thirty Years of Engineering and Architecture

The concise and non-exhaustive account of the company's activities limited to bridges only gives an idea of Stoelcker's much broader presence in the field of public works – works in which he adopted, where possible, innovative technologies and patents for reinforced concrete.

Simplex piles certainly constituted one of the company's prerogatives from its earliest Roman beginnings, and perhaps one of the main reasons for its bankruptcy in 1935 must also be attributed to them in a crisis that hit after a decade of very successful and diversified professional activity, the most important lines and construction sites of which are outlined below. Rome was a young capital city that, after the political and financial crisis of the collapse of the Banca Romana at the end of the 19th century and a slow recovery in the early years of the 20th century, had an interwar building sector characterized both by technological backwardness and resistance to new craftsmanship from building sites and workers, as well as by conflicts between the needs of the central government and the interests of the municipality. Constraints sometimes tied to political choices curbed the use, the expressiveness and the structural results of reinforced concrete (Ciucci 1989: 77).

In the second half of the 1920s, at least two works brought Stoelcker to the attention of an international audience, also thanks to his own self-marketing activity. In September 1930, he took part as a representative of major Italian companies in the 1st First International Congress for Concrete and Reinforced Concrete, held in Liège, Belgium[32]; on this occasion, he presented a report in which he illustrated in detail two of his works in Piazza Verdi in Rome: the new Officina Carte Valori dello Stato – Poligrafico (1926–1928) and the Casa dell'Automobile (1928–1929). In the former, the engineer worked on a mighty building, part of which had already been constructed to be used as the seat of the Court of Auditors (begun in 1911–1914), designed to be built in masonry. Although he had to use the existing foundations, Stoelcker managed through the use of reinforced concrete to provide the building with bright and spacious rooms, statically capable of accommodating the heavy machinery of the workshops and bearing the dynamic loads generated by their operation (Stoelcker 1931).[33]

The formally "hybrid" result of the building, that is an architecture characterized on the outside by the monumental eclecticism of a "European capital" and a functional interior, free from partition walls, punctuated by regular rows of pillars supporting the main and secondary trusses, was also replicated in the *ex-novo* construction of the Casa dell'Automobile, named after the joint-stock company founded by FIAT in 1925 with the support of the Italo-American Petroleum Company (Figure 2.3.12).

Built based on a design by architect Enrico Bacchetti, and demolished in the 1960s, the building destined for a private multi-storey car park at the forefront in Europe in terms of size and interior technology, presented itself as a huge block building modelled – albeit in simplified tones – by arcade fronts marked by a giant order (the main tripartite order) on an ashlar base and upper attic. These latter features led art critic and journalist Pier Maria Bardi (1900–1999) to place the building among the *passatist* works in the so-called *Tavolo degli Orrori* (*Table of Horrors*), a collage exhibited at the Second Italian Exhibition of Rational Architecture held in Rome in 1931.

The innovative character of its architecture, one of the largest car parks in the world, capable of accommodating over 900 cars on its ten floors (one underground and the last occupying only the inner part of the building), lay in its excellent use of the free solutions of the planimetric layout determined by the reinforced concrete structure – with the exception of the foundations in tuff stone, lime mortar and pozzolan – as well as those of the technological services (Figures 2.3.13 and 2.3.14). The static solution adopted by architect Bacchetti completely concealed

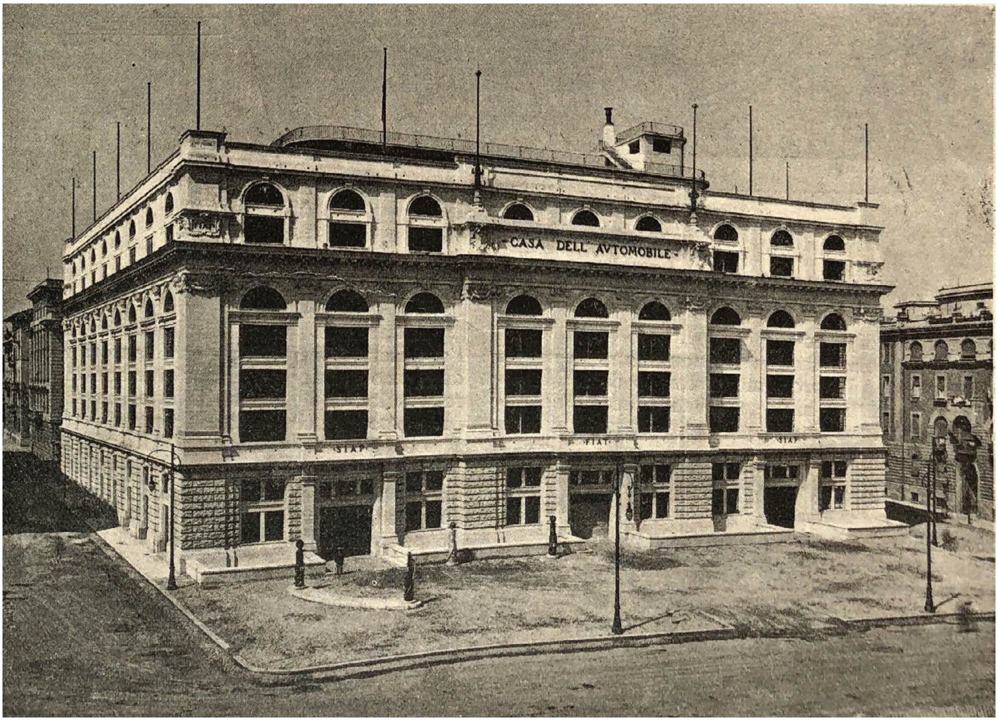

Figure 2.3.12 La Casa dell'Automobile, façade on Piazza Verdi, Rome.
Source: Stoelcker (1929).

the daring functionality of the interior space and, in particular, the dynamism imparted by the double-helix ramp allowing the cars access to the floors. These were elements which Stoelcker had already carefully discussed in the article published in 1929 in *L'Ingegnere. Rivista tecnica del sindacato nazionale fascista ingegneri e dei circoli di cultura degli ingegneri* (Stoelcker 1929; Ciranna 2021b), as well as in the aforementioned report.

The double-helix ramp, inspired as much by the Pozzo di San Patrizio in Orvieto as by the Château de Chambord near Blois or the multi-storey garage patent of the Turinese engineer Emilio Giay (1876–1951) of August 1925 (Olmo 1994: 12), was an element that attracted a great deal of interest in publications and exhibitions such as the I Mostra Nazionale dell'Ingegneria held in Rome in 1931 (Ferrario 1931). It was an architectural solution whose synthesis of structure and form showed a marked spatial quality, the result of Stoelcker's youthful formative experiences at the side of Mörsch, thus in the sphere of German engineering, more interested in the Monier structural system, consisting of two-dimensional elements – plates and vaults, rather than linear Hennebique – pillars and beams (Pogacnik 2006).

An ability to control and apply reinforced concrete in different circumstances found expression here in the elevations, just as it did in the contemporary or slightly later applications of the patented Zeiss-Dywidag (Z-D) system for thin, cylindrically shaped vaulted roofs, which the German construction company Dywidag – Dyckerhoff & Widmann – granted to Stoelcker in 1928 (Petry 1932: 280–281, 286; May 2015). Stoelcker adopted them for the roofs of two Roman garages: the first in 1928 for the taxi company Società Trasporti Automobilistici (STA)

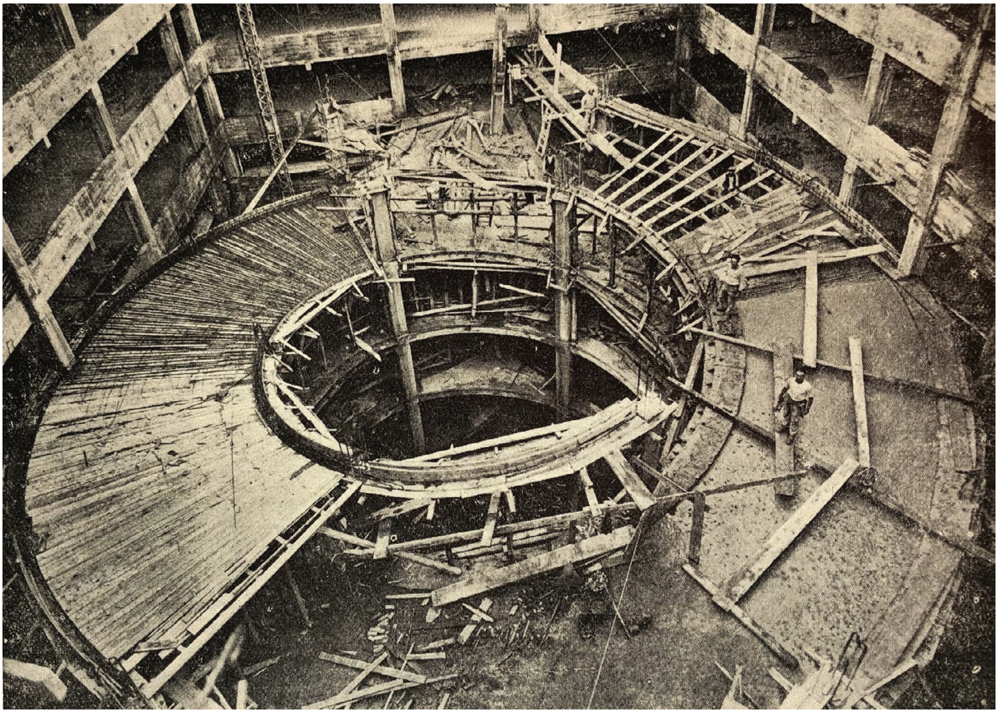

Figure 2.3.13 La Casa dell'Automobile in Piazza Verdi, Rome. The distribution ramp under construction.

Source: Stoelcker (1929).

in Piazza Ragusa, where he executed an 8-cm thin vaulted roof with 25-m span and an intrados with no visible beams (Figure 2.3.15) and the second in 1931 for the *Azienda delle Tramvie e Autobus del Governatorato di Roma* (ATAG) public transport depot in Trastevere.

The latter consisted of a two-storey structure covered with four thin vaults with a span of 14 m and a length of 41 m, each with skylights in the key along a length of 14 m (Russo 2017; Di Castelnuovo 1932: 158–160, 173–175).

The application of foreign patents and daring reinforced concrete solutions was not, therefore, limited to hidden structures, although in this respect, the paradigmatic construction of the water reservoir on via Eleniana near the Basilica of Santa Croce in Gerusalemme, intended for watering the streets and gardens of the Appio Latino, Tuscolano and Tiburtino neighbourhoods (Figure 2.3.16), is noteworthy.

Although the first planning and construction phases date back to the years 1884–1885, it was not until the late 1920s that it was actually built. As in the contemporary Piazza Verdi building site, the architecture of the exterior – a sort of monumental tetrapylon designed by architect Raffaele De Vico (1881–1969) – in tuff with brick courses (plinths) and architraves, crowning bands and travertine tympanums, concealed the four cylindrical chambers (with a total capacity of 2,000 m^3) built in reinforced concrete by Stoelcker, winner of the 1929 competition (Figure 2.3.17). In October 1933, his company also signed the contract for the completion works, consisting of both the reinforced concrete structures to connect the existing ones with

Figure 2.3.14 La Casa dell'Automobile in Piazza, Rome. The distribution ramp complete from the top.

Source: De Cupis (1929, pl. X).

Figure 2.3.15 *Officine della STA* in Piazza Ragusa, Rome.
Source: Russo (2017).

the framework of the perimeter walls, and the perimeter stone walls and structures, that is the traditional "Roman-style" masonry (Ciranna 2018, 2021a).

The solution adopted, including the expensive hidden system, and the use of Simplex piles for the foundations decisively accelerated the company's bankruptcy in 1935: it was the bankruptcy administrator himself who found the cause of the crisis in the stoppage of the Avezzano cathedral building site.[34] In 1929, Stoelcker was commissioned to build the foundations of the new cathedral in the Abruzzi town, which had been destroyed by the earthquake that hit the Marsica area in 1915. But his proposal to use Simplex piles due to the marshy terrain was met with firm opposition from the designer and director of works, engineer Sebastiano Bultrini (1867–1936). This resistance was then supported by the client, which led to Stoelcker's ousting from the commission and the termination of the contract, actions that were not followed up with the settlement of the sums committed by the company.

Figure 2.3.16 The water reservoir on via Eleniana standing out against the city walls, here coinciding with the Claudian aqueduct, Rome.

Source: The author.

Figure 2.3.17 Interior of the water reservoir on via Eleniana, Rome. The water tanks' profiles near the perimeter wall.

Source: The author.

And yet, the company's expertise in foundations in the presence of water was well known (even in Abruzzo): just consider, in addition to the bridges already mentioned, the dams on the Liri River (Figure 2.3.18) and, in particular, the one built in Sant'Eleuterio near Ceprano for the Società Mediterranea di Elettricità's hydroelectric plant. The work was completed in 1929 and inaugurated with great fanfare in the presence of the authorities in May of that year, an event filmed and documented by the Giornale Luce.[35] Stoelcker himself used it the following year to promote the company, including its photo in advertisements that appeared in specialized magazines such as *Il cemento armato* of 1930.[36]

Further proof of esteem for the company's technical expertise can be found in the assignments given to Stoelcker between 1932 and 1933 by Marcello Piacentini (1881–1960), chief architect on the building site for the new University City of Rome. In July 1932, Piacentini commissioned the Stoelcker firm to conduct tests on the geotechnical engineering properties of the subsoil to determine the type of foundations. Test results revealed a very irregular soil, which prompted Piacentini's decision to use a concrete pile system to be cast on site, an assignment to be entrusted to specialized companies with patents and suitable machinery.[37] The companies Stoelcker and Ferrobeton, both qualified in the use of Simplex piles, were the winners of the competition and divided up the six buildings envisaged by the tender, with Stoelcker taking Lot A (the Rectorate, Law and Humanities buildings) (Figure 2.3.19) and Ferrobeton Lot B (Mathematics, the Institute of Hygiene and the Institute of Physics).

Figure 2.3.18 Dam on the Liri river at Sant'Eleuterio near Ceprano in the advertisement for the Impresa Stoelcker.

Source: *Il cemento armato*, XXVII, 2, February 1930: 20.

Figure 2.3.19 Pile driving structure used by Stoelcker for the construction site of the University City of Rome.

Source: Cover of *L'organizzazione scientifica del lavoro* magazine (year VIII, fascicule V, May 1933).

Widespread rumours about Stoelcker's financial fragility and the whiff of bankruptcy were probably among the reasons that prevented the company from acquiring further orders for the elevated university buildings.

As already mentioned, Stoelcker resumed his activity after 1937 and continued it until the end of the war with important assignments. He also participated together with other Italian companies in the construction of one of the three complexes that formed the Auschwitz concentration and extermination camp – to be precise, the camp founded in October 1942 in the town of Monowice in Poland, located near the Buna-Werke synthetic rubber plant, owned by I. G. Farben, to which the deportees were destined (Mantelli 1992: 274).[38]

After an apparent post-war lull, company activity resumed with important contracts – in addition to those already mentioned for bridges – signed in the mid-1950s with the Municipality of Rome. The first in 1954 concerned the new Forte Antenne transformation and distribution centre located in Acqua Acetosa; the second in 1955 was the construction of artefacts for Azienda Comunale Elettricità e Acque (ACEA) for a second steel pipeline to cross the Tiber Valley with the Peschiera Aqueduct.[39]

Additionally, in 1956, the company was involved in the construction of the Autostrada del Sud in the section between Pompei and Catellammare,[40] a work that finally consolidated not only Stoelcker's commitment but also his professional life in an Italy that was then in the midst of an economic boom.

Notes

1 Historical Archives of the Rome Chamber of Commerce, *Ditta Rodolfo Stoelcker*, *Company Register,* folder no. 3437, Registration Certificate of 20 October 1914.

2 Known in Italy as Rodolfo Stoelcker, Rudolf Stölcker was born on 22 February 1880 to Carlo and Teresa Wehrle. This is recorded in the Criminal Records Certificate issued by the Court of Rome to Stoelcker on 14 September 1935, in the State Archives of Rome, *Tribunale fallimentare*, file no. 1192 bis.

3 The city in which he probably met his future wife Antonietta Maranghi, a native of that city, as well as his brother-in-law, the accountant Carlo Maranghi, known in Rome as a player as of 1912 at the Lazio football club, who would be instrumental in the years of the First World War for his first important Roman commission, the foundations of the Ministry of the Navy.

4 On the spread of reinforced concrete in Italy, see Iori (2001: 16–20, 51).

5 The engineer Oscar Huber was a specialist in structures and a pupil of Emil Mörsch, who had employed him at Wayss & Freytag in 1906; he carried out his entire career in the Italian subsidiary which moved from Genoa to Rome in 1912 and in 1914 became independent, at least in name, from the parent company, becoming Ferrobeton Società Anonima Italiana. A brief profile is outlined in his obituary (Straub 1951: 733).

6 See, among others, Di Pietro (2018: 564–565).

7 The regulations remained in force until April 1922, when new ones were proposed and converted into law in 1925.

8 Theory supported by his work *Der Betoneisenbau* of 1902, widely disseminated and translated into several languages. For the Italian translation, see Mörsch (1910).

9 The quotations are taken from *Istanza di concordato preventivo a seguito di fallimento of 18 September 1935*, in the State Archives of Rome, *Tribunale fallimentare*, file no. 1192bis, f. 14880, vol. 1.

10 On the opposition to Stoelcker and the attacks in newspapers on both Ferrobeton and Stoelcker, see also the bibliography in Ciranna (2017) and Ead. (2021b), in particular pp. 368–369.

11 Prescribed in the competition notice of 18 December 1913.

12 On the different phases of construction and reconstruction of the bridge, see in particular Ciranna (2016: 300–301).

13 *Archivio Storico Capitolino* (ASC), *Contratti*, *contratto d'appalto del 18 novembre 1944* rep. no. 27596, Contract for work to repair the Tito Tazio bridge over the Aniene river entrusted to Mr. Rodolfo Stoelcker by the Municipality of Rome. In the power of attorney dated 6 August 1943, it is specified that Stoelcker is an Italian citizen resident in Viale Regina Margherita 262. In this power of attorney,

Mrs Antonietta Maranghi di Giuseppe in Stoelcker, born in Genoa and domiciled in Rome viale Regina Margherita 263, and Maria Geraci fu Decimo, domiciled in Rome, who administer his property, are appointed as Stoelcker's attorney general. The contract was awarded by private treaty for £300,000 Italian lire following resolution no. 792 of 23 October 1944. From the special tender specifications, we learn that the repair work following the mine explosion included:

> the demolition of the damaged structures of the bridge and their reconstruction, the reinforcement of some members by injecting cement under pressure, the demolition and relative reconstruction of part of the parapets of the bridge, the resurfacing of the road surface in the damaged part, the supply of various materials, as well as timber and labour, etc.

14 A collection of photos and a few news items is available at www.casoli.info/casoli/cartoline (accessed 19 September 2022).

15 Some news is available at: www.cdsconlus.it/; www.costantinojadecola.com and http://old.comune.minturno.lt.it/museo (accessed 19 September 2022).

16 For the bibliography and archival sources cited in reconstructing the different phases of the bridge construction, see in particular Ciranna (2019a: 36–37).

17 The bridge was solemnly inaugurated in the summer of 1933. Cf. Archivio Istituto Luce, Giornale Luce B0322, 1933 – "Ricco di archi e colonne, il nuovo Ponte del Littorio sul Pescara sostituisce l'insufficiente ponte in ferro ora demolito. Il ministro dei lavori pubblici lo ha solennemente inaugurato" available at: https://patrimonio.archivioluce.com/luce-web (accessed 12 December 2022).

18 The text by Cecchelli, C. (1931) consists of a brief technical description with photos of the construction site. In 1930, Impresa Stoelcker was awarded two contracts for embankment works in Vallerano, namely the first for the "Raising of the carriageway and modification of the parapets of the bridge over the Vallerano ditch at Tor di Valle to protect the Via del Mare from the Tiber floods" (22 April) and the other for the "Reinforcement of the carriageway and modification of the parapets on the Malafede ditch" (15 July), in the State Archives of Rome, *Ufficio Speciale per il Tevere e l'Agro Romano, Sistemazione sponde*, file no. 210 (1930–1936) Vallerano, Malafede.

19 Florence State Archives, 011/70/I, file no. 630, ins. 1, Azienda Autonoma della Strada. Concession for the construction of a bridge over the Greve Torrent at "Casellina" for the variant of State Road no. 67. There is an earlier project dated 5 April 1930 signed by SAIS Società Anonima Imprese Stradali Roma Viale Regina Margherita 262, that is the company founded by Stoelcker on 18 January 1929 which in 1931 transferred its registered office to Milan. On the latter, see Ciranna (2021b: 381–2).

20 See, for example, Regione Toscana (1933: 227).

21 The documentation is kept in the Prato Municipality Archives, *Opere pubbliche, Strade, Passerella pedonale sul fiume Bisenzio*, file no. 969 (the folder also bears the number 88).

22 Here as in other entries that follow, Stoelcker used the plural "bridges" without specifying the exact number and location.

23 On the bankruptcy, see Ciranna (2021b: 384).

24 On 19 December 1935, a contract was drawn up between the Province of Rome and the Rodolfo Stoelcker Company in bankruptcy concerning the construction of a new overpass on the State railway at Via Casilina. In the contract, Stoelcker was represented by Dr Ettore Felici, curator of the bankruptcy of the company. Stoelcker had obtained the contract on 20 December 1933, registered in Rome on 8 January 1934 for the sum of £670,000. Following a variation requested by the Railways, a new project for the work was approved for an amount of £1,170,000. In ASC, Contratti, 20 December 1933, there was the construction of a flyover on the Ferrovie dello Stato tracks near Via Casilina and, on 19 December 1935, there was the construction of a new flyover on Via Casilina. In addition to this bridge, Stoelcker was also allowed to continue the construction of the piezometric tower for the Acquedotto Vergine in Salone, the contract for which was dated 28 June 1934.

25 ASC, *Contracts,* 5 November 1939 rep. 21895, *Contract for the construction of the new bridge over the Tiber at San Giovanni dei Fiorentini*, value of works £7,700,000. The contract was consequent to the completion of the tender of 28 April 1939.

26 On the contract for the four bridges awarded to this company, see D'Onofrio (1968); Pietrangeli (1964: 295–300). Of the four bridges planned – the Rotto bridge (to be completed in the missing section), the one at San Giovanni dei Fiorentini, at Ripetta and at Ripa Grande with access to the San Paolo road – only the first two were built. The Fiorentini bridge was completed in 1873 in a Rome that had just become the capital of Italy.

27 Architect Bronzetti had also designed the bridge over the Castelfusano Pond Canal, built by Impresa Stoelcker in 1933, see ASC, *Contratti,* 7 June 1933 rep. N. 10049, "Contratto tra il Governatorato di Roma e il Sig. Stoelcker Rodolfo". Construction of the bridge over the Stagno canal at Castel Fusano, following resolution no. 2284 of 25 April 1933, contract by private treaty for an estimated cost of £105,945.31, granted for a price per body of £63,000. See also contracts dated 9 March and 9 May 1934.

28 The quotation is taken from the Special Tender Specifications kept in the archives of the former V Department, Rome, now Dipartimento Sviluppo Infrastrutture e Manutenzione Urbana-Centrale Unica Lavori Pubblici (SIMU), folder 21 Fiorentini. Here, it is specified that the demolition of the suspension bridge would take place after the new bridge was opened to pedestrians and would include

> in addition to the dismantling of the iron structures, the demolition of the piers also in the underwater area until the normal section of the riverbed was restored, the demolition of the terminal aediculae on the banks, the complete restoration of the embankments and any other accessory work.

29 Archivio Storico Capitolino, *Contracts,* 8 October 1943, rep. no. 26747, contract between the Province of Rome and Mr. Stoelcker Rodolfo. Subject: contract for cement injections necessary for the extraordinary maintenance of Ponte Risorgimento. Amount: 99,500 Italian Lire. The contract was by private treaty following resolutions 2380 of 13 August 1943 and 2892 of 7 October 1943 and in accordance with the special specifications attached to the contract. See also there, contract of 25 September 1942 and that of 6 October 1944 for the completion of the works at Ponte Risorgimento.

30 The arch has a cellular structure consisting of a 22- to 30-cm-thick intrados slab, three 35- to 45-cm-thick vertical septa and a 22- to 30-cm-thick extrados slab – all connected by 13 stringers with a constant thickness of 20 cm.

31 See here nos. 34–35 for the bibliography and archival sources in the cited texts.

32 The companies invited, in addition to Stoelcker, included Ferrobeton, Vianini and Eternit. See A.G.B.: 1930.

33 The original project was by architect Garibaldi Burba (–1925), the conversion into workshops was followed by architect Arturo Larderel. See State Archives of Rome, Roman Civil Engineering Office, file nos. 32–48 and 406.

34 Bankruptcy was declared in September 1935, but the signs of the company's financial difficulties were apparent three years earlier (Ciranna 2021b: 375).

35 In Istituto Luce, Giornale Luce A/A0342, *Inauguration of Ceprano power station*, date: 05/1929 film code: A034205. Available at: https://patrimonio.archivioluce.com/inaugurazione-della-centrale-elettrica-ceprano (accessed 24 September 2022). The work is also included in the aforementioned list submitted by Stoelcker to the municipality of Prato for the invitation of tender for the footbridge over the Bisenzio, see no. 25.

36 The advertisement appeared in several issues of the year among various advertisements, see *Il cemento armato*, XXVII, 2, February 1930: 20.

37 A necessary choice, in Piacentini's opinion, both to meet the delivery time indicated by the Duce within three years and to satisfy the demands of modernity, innovation and comparison with international circles. Cf. Ciranna (2019b).

38 Concerning the agreement between the Federazione Nazionale Fascista Costruttori Edili (FNFCE) and IG Farben and HGW (Hermann Göring Werke), Mantelli mentions the contract signed on 14 March 1942 which committed a consortium of 40 Italian companies, with the supply of 8,635 construction workers as well as 21 cooks and interpreters. The contract is in print: Federazione Nazionale Fascista Costruttori Edili, *Contratto per l'esecuzione di lavori di costruzione in partecipazione con imprese germaniche, nei cantieri di Heydebreck, Blechhammer e Auscwitz*, Tipografia del Gianicolo, Rome, 1942. See also Fertilio, D. (18 March 2001), 29; http://giuseppemarazzini.blogspot.com (accessed 25 September 2022).

39 ASC, *Contracts,* one concluded on 24 February 1954 and registered on 10 April and the other on 2 March and registered on 30 March 1955.

40 The engineer Mario Neumann, born in Rijeka in 1920 (who was Stoelcker's son-in-law, having married his daughter Teresa Maria), moved with his family to the USA in 1957 and was engaged on this site. I thank his son David for providing the author with the relevant documentation.

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Chapter 2.4

Public Works Contractors in Antwerp in the 19th and 20th Centuries

Inge Bertels and Jelle Angillis

Introduction

Public works contractors constitute a vital link in the public building process. Over the last two decades – and specifically within the Belgian context – multiple scholars have studied how contractors as a growing group of professionals in the construction industry gradually obtained strictly defined positions in a dialectical process with related professions, including that of architects and engineers (see among others: Bertels 2008; Culot et al. 2018; Degraeve 2021; Dobbels & Bertels 2018; Dobbels 2021; Vandyck 2020). In this contribution, the Belgian city of Antwerp is taken as a case study to analyse how this growing professionalization impacted the organization of public works in practice. During the 19th and 20th centuries, Antwerp underwent a significant transformation in which public works were an effect as well as a cause (Bertels 2011). At the end of the ancient regime, the port city regained its position as an economic metropolis, and with the demolition of the city walls in the second half of the 19th century, the urban fabric burst out of its centuries-old boundaries (Figure 2.4.1). During the last 200 years, not only has the port area expanded as one of the main arteries of the national economy, but the city has also managed to consolidate its political, social and economic position within the country. Building and renovation, with public works as one of the main drivers, have played an unmistakable role in these developments.

The city has pursued an active building policy, but the actors involved, such as architects and contractors, have also been happy to make use of this evolution to develop their own métier within the context of city building. In this chapter, two time periods are presented in more detail. This first part of this chapter examines how in the second half of the 19th century, part of this specific group of "builders" – those who were active in public works – can be defined, in both quantitative and qualitative terms, and within the period of study and the context of Antwerp. What potentiality of public works contractors was available? How did these contractors relate to other professions within the building industry? And how did these (public) building contractors participate in the redefinition and (re-)positioning of the roles of "architect", "engineer", "contractor" and "craftsman"? In the second part of this chapter, Jelle Angillis focusses on the second half of the 20th century. He shows how political and economic decision-making created a basis for public works that would further shape the city and then uses a case study to highlight how one local contractor – Frans Verachtert NV – was able to develop within that urban expansion.

DOI: 10.1201/9781003368656-14

Figure 2.4.1 Antwerp urban city extension and transformation of the former military terrains, Van Bever, 1864.

Source: Felixarchief – Stadsarchief Antwerpen, 12#3460.

Nineteenth-Century Attempts to Professionalize Public Works Contractors

In general, the building industry is known to be a varied and complex sector. Its components range from private housing and industrial building to public works and include temporary employees, craftsmen, material suppliers, general contractors, surveyors, architects and engineers, among others (Claes et al. 1990). A question that arises is whether there is a specific and distinguishable group (in quantitative and/or qualitative terms) within this myriad variety that is "specialized" in the execution of public works projects. At the national level, 19th-century national counts "indicate" that the share of the building industry within total Belgian employment evolved from 1.5% in 1846 to 3.8% in 1896 (Statistique de la Belgique 1846–1896). Jos Delbeke calculated that the share of this sector at the Antwerp urban level was even more notable, having grown from 9% in 1846 to 15% in 1896 (Delbeke 1985: 2014). However, these quantification efforts remain inadequate. Thus, Inge Bertels also analysed various qualitative historical sources, including building specifications, tenders, contracts, disputes and legal transactions, most of which are conserved in public archives, including the Antwerp City Archive, the Antwerp Provincial Archive and the State Archive. Research shows that contractors used the same public regulation and normalization as an information source and as a "standard" in disputes between contractors and private customers (Bertels 2008). The investigation also explored education-related (written and published) sources (Academy of Fine Arts, Antwerp City Archives, Industrial Schools, Antwerp City Museums and Depots).

In Search of a Legal Position in a Period of Growing Construction Demand

In the Belgian context, above all in the 19th century, the legal and socio-economic position of contractors was conspicuously weak. Most building contractors were self-employed, and there was limited distinction in practice between architects and contractors. This legal situation dated from the turn of the 18th century. The main legal source, the Code Civil or Code Napoléon (1804), offered no proper distinction between "architect" and "contractors", and related articles mention *architecte et entrepreneur* or *architecte ou entrepreneur* (Van de Vijver 2000: 58, Delecourt S.D.: 7–8). The preceding discussions demonstrate that the combination architect–contractor was explicitly added, as in some regions the term architect was not used. The French Le Chapelier Law of 1791 was extended to Belgium in 1795 and likewise aimed to dispense with the socio-economic organization of the Ancien Régime. This resulted in the prohibition of traditional guilds and trade associations, including all building-related organizations. However, these associations became legal when Belgium became independent in 1830, although trade unions remained prohibited until 1866. In 1809, the first society for joiners and carpenters, the Maatschappij van schrijnewerkers en timmerlieden, was established in Ghent (Dambruyne et al. 1989–1992: 218–219), and similar initiatives arose in Antwerp. The association of Antwerp craftsmen, for example, was established in 1837 as the Gilde van den H. Jozef of Vereeniging van Katholieke Ambachtslieden, and its name was changed in 1857 to Koninklijke Gilde der Antwerpse Ambachtslieden (Stad Antwerpen 1907). Much as a consequence of their inheritance, the first professional organizations of this period were restricted from focusing on formal professional organization; they instead developed charitable activities and health provisions and devoted time to providing services for the (religious) education and recreation of their members (Bertels 2008).

During the 19th century, the construction industry developed apace. At the beginning of the century in Belgium, these municipal services only regulated design and building control. Construction work itself was rarely done in-house by craftsmen employed directly by the public works service. Rather, the work was generally outsourced to the private sector by putting it out to tender. Additionally, the fiscal requirement for the government to minimize the costs of such provisions made it necessary to standardize the process of work organization. This would have consequences for hierarchies in the construction industry. From the start, the transfer (from public works to the contractor) of the organization of on-site construction stimulated the creation of the so-called general construction firm, the *entrepreneur général* (Figure 2.4.2).

Henceforth, building contractors had more opportunities to participate in on-site decision-making. At the end of the 19th century, the *Pandectes Belges*, an encyclopaedia of Belgian legislation, clarified the evolution of the changing role of building contractors. Whereas the architect remained the initiator of design and, moreover, retained ultimate authority for the work undertaken, the contractor increasingly held overall responsibility for the work's organization and execution:

> In construction companies, a distinction is made between the architect and the contractor. The architect is generally the person whose profession consists of drawing up plans and

Figure 2.4.2 Demolition of the historic centre and dismantling of "de werf" by contractor Couvreux & Hersent, *ca.* 1880.

Source: Felixarchief – Stadsarchief Antwerpen, Foto-Album#61.

> specifications and directing the work; the contractor is the worker who, in return for a salary, undertakes to carry out the work agreed upon by himself or by persons he has on hand. Both have their share of responsibility in the execution of the work to seek and use the means of execution of the plans designed by the architect, and to assemble and use the materials provided for and prescribed by his contract so as to firmly establish the work according to the forms and dimensions of the plans he has received. The understanding of his responsibility requires him to be vigilant at all times. The contractor needs not only great energy, but also extensive knowledge and despite this, his fortune is still exposed to the ever-changing fortunes of the companies.
>
> (*Pandectes belges* 1891: vol. 37, col. 137, art. 5) (translated from French)

A clear legal regulation would not be established until the 1930s and 1940s (Dobbels & Bertels 2018).

Apart from national legislation, additional local regulations were developed by local public administrations and entered into the *conditions générales* (general clauses, *algemene voorwaarden*) of building specifications (*cahier de charges, bestek*). These sources contain information on additional qualifications for the Antwerp public work contractors (Figure 2.4.3).

Within the period under consideration, the most important were a surety (*caution, borg*), competences/capability and a registered (office) address in Antwerp. Several contractors lived on credit and advances. The continuity of projects became vital. The city government rarely rejected a contractor's submission if he could present a surety. The definition of the surety

Figure 2.4.3 Rectification of the Scheldt quays to improve port functionality by contractor Couvreux & Hersent, circa 1880.

Source: Felixarchief – Stadsarchief Antwerpen, Foto-Album#61.

evolved from a mortgage ("Guarantee in real estate located in the province to the value of six thousand guilders mortgage") to a personal surety ("The contractor will provide a personal guarantee, approved by the college, which will remain the guarantor of the works, and is jointly and severally liable for everything that may concern the company") (SAA Aanbestedingen, translated from French). After family members, fellow contractors most often expressed willingness to stand surety. To be sure, vouching for someone's reliability was not without risks. The decennial liability for architects and contractors – the first quality control system, as declared in the French Civil Code (articles 1792, 1793 and 2270) – was adopted into the Belgian Civil Code and persists today. In Antwerp, frequent appeals were made to this rule during the period under consideration. However, public maintenance contracts in Antwerp occasionally deviated from the decennial liability rule and declared a one-year liability instead (Bertels 2008). The second requirement concerned the qualifications of submitting contractors. Due to an absence of professional standards, a contractor's competence was judged solely the quality of previous work: "no one shall be admitted as a tenderer who, having previously closed or been awarded work or supplies on behalf of the city or another public administration, has not fulfilled his contract" (SAA Aanbestedingen, MA 80.707, translated from French). A letter from city architect Pieter Dens, dating 16 February 1864, to the Antwerp City Council shows that a "best practice list" of Antwerp public works contractors and craftsmen was circulating at the public works service (SAA Aanbestedingen, MA 1019). This list included at least 38 names and was primarily intended for smaller and urgent jobs. According to Dens' letter, the application of the list had "generally provided good results". It is not surprising that the Antwerp municipality was vehemently against it, as "there might still be other entrepreneurs who would come forward on terms favourable to the city's interests" (SAA Aanbestedingen, MA 1019). It is clear that the municipality wanted to exert maximum control and influence in these matters. The municipality maintained the right to exclude contractors to prevent mala fide practices and to further collaboration with public works contractors: "reserves the right to reject bids from individuals who do not have the required creditworthiness, character and knowledge to be a contractor" (SAA Aanbestedingen MA 80.351). As such, the municipality always had an argument to fall back on. This also re-opened the door for arbitrary actions. Third, the requirement for an officially registered address in Antwerp carried a legal advantage for the city rather than protectionist economical intent. In this way, legal disputes could be fought in the local court. This did not exclude non-Antwerp citizens but explicitly demanded that they be officially registered within the city. It was not until 3 February 1947, with the "contractors' law" (*Wet op de erkenning van de aannemer*), that legal recognition of contractors was definitely established (Flamme 1996, 121–145 and Dobbels & Bertels 2018). This regulation followed the "architects' law" of 20 February 1939, whereby the title and profession of architects became protected (Verpoest 1990: 112–129; Dobbels & Bertels 2018).

Growing Needs for Alternative Training and Education

During the second half of the 19th century, the work of contractors became characterized by increasing complexity. New contexts required coordination of on-site work, and the required tasks became more diverse. The transition from artisan-builders into general contractors and subcontractors required that contractors develop an increasing familiarity with multiple skills, ranging from craftsman and supplier to organizer, coordinator and negotiator. The need for an alternative and more focused training process became a higher priority. But it can be taken for granted that many contractors continued to learn on the job as craftsmen (Willemen & Asselman 1966). Such training would have remained quite similar to that undertaken during the Ancien Régime, when apprentices learned under the guidance of experienced master craftsmen (De Munck 2001: 569–607). A closer look at the training of contractors in Antwerp shows that many contractors undertook multiple and diverse training regimes. Some contractors trained formally as architects or engineers. Others received craft-training but completed this with evening classes at local drawing schools.

The Antwerp Royal Academy of Arts (1663) and other academies experienced an important flow of students working towards professions in the building sector (Van de Vijver 2000: 59). Numerical data for the period 1854–1863 clearly demonstrates this: 34% of students (456 students of 1,318 in total) focused on the building industry. Of this 34%, only 9% (41 students) began careers as architects or designers, while 70% (317 students) became employed as joiners or carpenters, 14% (66 students) as stonecutters and marble workers, and 7% (32 students) as plasterers (Antwerp Royal Academy of Fine Arts Rapporten 1854–1864). An interesting example is Joseph Lefèbvre. After finishing his grammar school education at the Antwerp Royal Athenaeum, he began working in the building firm of his godfather Eugène Riche. In order to get promoted, Lefèbvre attended evening classes at the Antwerp Royal Academy (*lessen der bouwkunde*), after which he started his own construction firm and worked on a broad variety of projects (conservation, maintenance and new building projects; railways, churches and public building projects) (Van de Venne 1895).

Far from simply broadening the content of existing training provisions, the economic and social transformation of 19th-century Europe also spurred further development and experiments in vocational training. One example of this was a new type of training called *technical* *education*. This label covered various educational programmes that trained manual workers in a range of sectors, including agriculture, domestic trades and industry. The evolution of this technical education in Belgium has been examined primarily in its pedagogical aspects (see among others Dezutter & Goetinck 1979; D'Hoker 1980; Grootaers 1994; Bertels 2006). Industrial schools and faculties first emerged in rapidly developing and industrialized areas, including Liège (1838), Ghent (1838), Huy (1838), Verviers (1841) and Charlerloi (1845). They were allied to specialized regional industries, such as the textile industry in Ghent or the mining industry in Mons. Multiple technical schools also provided theoretical and technical education for craftsmen in the building industry. By the end of the 19th century, 40 such industrial schools (*Nijverheidsscholen*) existed in Belgium. Nearly half (18 of 40) were in the Hainaut province; the rest were mostly spread throughout the major cities of the Belgian provinces (*Rapport sur la situation de l'enseignement industriel et professional en Belgique 1897*). In Antwerp, a private industrial school was established in 1862. This school provided a predominantly theoretical education that specifically included training employees of the building industry (Figure 2.4.4). It was founded between 1860 and 1861 as a school for ornamental and architectural design but developed from its original designation to an industrial school in 1862 (SAA MA 237–18).

The driving force behind this private initiative was the aforementioned architect–surveyor Hendrik Altenrath. His comprehensive scholarship and practical expertise are evident in the curriculum vitae and letter of application he submitted for the vacant post of Antwerp City Architect in 1862 (SAA MA 867/1–2). In his own practice, he had experienced a shortage of

Figure 2.4.4 Façade of the former Nijverheidsschool at Paardenmarkt Antwerp, circa 1925.

Source: Felixarchief – Stadsarchief Antwerpen, Foto-Of#2234.

skilled workers and understood the need for technically trained craftsmen. In order to meet the needs of local employers, the industrial school provided evening and weekend courses. Its remit was straightforward: "to disseminate scientific and industrial knowledge and create the opportunity for everyone to qualify in their professional discipline" (SAA MA 237 18A, translated from French). In providing supplementary technical training to eligible practising craftspeople (albeit primarily male students who were literate and over age 15), the institute offered a broad technical education for many prospective students. Students could attend courses on history, arithmetic, algebra and bookkeeping on weekday evenings; and on construction, mechanics and industrial drawing courses on Sundays. In a notable departure from general practice, the courses were exclusively taught in the students' mother tongue (Flemish or *Vlaamsch*). According to Altenrath, in order to be effective, "training must be in Dutch. The mother tongue is the language that communicates with the powers of comprehension, the only one which is connected with clarifying notions, which is respectably educating, which can enlighten people's brains with clear concepts" (SAA MA 237 18A). The industrial school swiftly became popular: in the years 1860–1861, some 40 students enrolled on the winter course, but by 1864–1865, enrolment had expanded to 310 pupils. Yet the school became a victim of its own success. Its rapidly increasing enrolments and escalating costs of provision forced its private investors to bequest the school to the city of Antwerp in 1866 (SAA MA 237 18A). The institution became part of a larger, pre-existing public educational network managed by the City of Antwerp. The courses were initially on weekdays from six till eight in the evening and were combined with the drawing courses on Sundays. The weekend courses were dropped in 1876, and drawing was reintroduced into the evening courses. As a result, courses were extended from six till nine in the evening. In 1869, an elaborate school programme was adopted by the Directorate and was further adjusted on an annual basis. For students working in the construction industry, Antwerp was regarded as being at the cutting edge of applied technologies and as the ideal laboratory for experimentation and familiarization. Students thus studied not only the organization of public works but also the technology, scaffolding, building equipment and machines used to deliver such services. Even standardized building specifications drafted by the city architect and engineers were studied (Bertels 2006; Bertels & Dobbels 2015).

Another form of technical education was also developed alongside the industrial schools: vocational training. Vocational schools primarily or exclusively provided practical training, and their programmes aimed to counter the shortage of practical training available on site. In most cases, their programmes were organized during the day. Furthermore, unlike vocational training, engineers' and architects' training most often offered direct access to a particular profession. The programme at the industrial school, however, provided craftsmen and contractors with an additional theoretical training, itself a means to social and professional mobility. Together with the establishment of their proper professional organization, the provision of an appropriate training for contractors, as provided in the industrial school, strongly supported contractors' professionalization throughout the 19th century.

Development of Professional Networks and the Establishment of a First Union in 1874

Nevertheless, even under such improved educational conditions, contractors still faced profound difficulties. Cooperation between local government officers, city architects and engineers was far from ideal. Moreover, contractors remained shackled by a bureaucracy stemming from previous legal requirements. Another direct result of this growing polarization between architects and supervisors, on the one hand, and contractors and craftsmen, on the other, was a growing need for a proper professional organization that would defend the common interests of the latter group. A pioneering role would be played by the Cercle des Entrepreneurs de Travaux Publices (Maatschappij van de verschillige ambachten en bouwstielen), founded in Antwerp in September 1874 (ABC Statuten 1874). In 1881, this Antwerp union, along with the equivalent unions in other Belgian provinces, decided to establish a Belgian-wide confederation of contractors. The Antwerp union played an important, if not decisive, role in the formation of this umbrella organization covering each regional association (Venstermans 1954: 44). The members of the Antwerp *Cercle* presented themselves as *les entrepreneurs de travaux (publics)* (*aannemers van publieke werken/gebouwen*) or public works contractors and were, as far as could be ascertained, "trained" in building-related trades. Most worked as an *entreprise général* or general contractor. Unlike the master builders they supplanted, their workforce included all main trades, although they were prepared to call in subcontractors. From 1874, several petitions were launched via direct correspondence with the Antwerp government and through publication within professional periodicals such as the *Chronique des travaux publics* (ACB, *Minute book* 1874–1882, SAA, MA 1019, 1876–1881. *Chronique des travaux publics*, 11 April 1880, 4 September 1881 and 18 September 1881). Problematic issues such as late communication of public tenders and related documentation were vigorously discussed and challenged. In 1881, the Antwerp union, together with the unions of Brussels and Liège, and those unions on the verge of (re-)organization (Ghent, Verviers, and Charleloi), decided to establish a federal Belgian confederation as an umbrella organization. The Antwerp subsidiary played an important role in this process (see Venstermans 1954: 44 and Dobbels & Bertels 2018). International congresses (*Congrès international des entrepreneurs*) were organized as of its first year. Besides organizing congresses, other central items included protection of professional standards and the legal position and recognition of contractors (finally obtained in 1947), elements which remain crucial in their current policy.

The Antwerp *Cercle* was led by an executive committee, which in 1874 consisted of six members: J. Hertogs (honorary chairman), A. De Pauw (chairman), André Hertogs (vice-chairman), Alphonse Hertogs (secretary), E. Van Hengel (treasurer) and Michel Looymans (official). A short introduction to some central figures offers a glimpse of the socio-economical and political position of the Antwerp contractors and demonstrates that a contractors' organization like the *Cercle* represented individuals with heterogeneous profiles and ambitions. André Hertogs, for example, played an important role at both the local and national levels. Following the Antwerp model, Hertogs enthusiastically contributed to establishing a Brussels union of contractors, which came into being in 1879. Two years later, he was appointed as the first chairman of the Federal Belgian confederation of contractors. His brother, Alphonse Hertogs (1843–1908), was the first secretary of the Antwerp *Cercle* and represented a "politically engaged contractor". As a member of the "Liberal Flemish Alliance" and later of the "Liberal Association", he was elected in 1891 as Alderman of Public Works and as mayor of Antwerp in 1905. He was thus perfectly positioned to stimulate and defend the entrepreneurship of Antwerp contractors at the local level. A completely different profile is that of Michaël Looymans (1829–1908), an official of the *Cercle*. He was known as a "charlatan" and a "constructor of simulacra", and his attempts at designing or building major Antwerp public works and buildings were unsuccessful, as were his applications to become City Architect in Hasselt and in Antwerp. His participation in the *Cercle* can be interpreted as a personal attempt to obtain a better socio-economical position (Bertels 2008). Yet not everyone lauded the growing power of contractors. In the last quarter of the 19th century, many architects were highly critical of the role of general contractors. In 1879, Ernest Allard (1849–1898) in *L'Emulation* criticized the "bewildering" variety of 19th-century Belgian building contractors:

> Today, everyone bids for the execution of works of art. Bankers, brickmakers, merchants we could even say "umbrella merchants", if the term were not, despite all its veracity, presented in a form that was perhaps a little too brutal. Suppose it is a question of building a town hall, a church, a museum, a court house or an exhibition centre. In the work to be carried out, there is decorative sculpture, ornate marble, ornaments to be placed in the cornices, architraves, etc. etc. What does the contractor who is not serious about coming in first, i.e. the lowest bidder, do? He consults some ornamentalist, ex-moulder, and will be much more concerned with obtaining a commitment on soft costs than with ensuring if the contractor is doubled of an artist, if his work will reach the standard of what one is entitled to expect.
>
> (Allard 1879, col 4, translated from French)

For Allard and many others, the increasing application of the technique of general public tenders was "the root of all evil", whereby quality was compromised for economic efficiency and rational organization. In such opposing views, the general contractor was seen as an economic aggressor, elbowing himself into a position between that of an architect and craftsman.

1945–1985: Antwerp's Post-War Political, Economic and Social Climate Shapes and Reshapes Public Works Contracting

The first part of the chapter highlighted not only how public works contractors sought to consolidate their position within construction practice through professional organizations, among other things, but also how training and networking fuelled the growth of the profession during the 19th century. Addressing these themes not only revealed the local anchoring of the profession, but it also tentatively showed the importance of the surrounding political, social and economic context. It therefore raises the question of how much that (local) context determined the evolving position of involved contractors within public construction practice and specifically in the second part of the 20th century. In the five decades after the Second World War, Antwerp underwent a veritable metamorphosis in which building and rebuilding played a major role. The global conflict had heavily affected the city's built environment, with reconstruction and quality housing having long been a spearhead of the local political system. In addition, economic revival was also on the agenda, with, among other things, the expansion of Antwerp's port facilities as a cornerstone. However, the end of the 30-year period of growth known as *Les Trente Glorieuses* and the economic crisis of the 1970s had a significant impact on public spending, with new strategies emerging in the construction sector and specifically among contractors with a focus on public works. It was within this political, economic and social climate that public works contractors not only were shaped but also gradually had to reform and adapt. This section successively discusses the evolution of Antwerp's built environment between 1945 and 1985 with a focus on public works, situating the 1980s as an important turning point. It then attempts to analyse the interplay between the surrounding political, social and economic factors and the individual development of the contractor by contrasting a case study of one public works contractor, Frans Verachtert NV, within this evolution. How important was a company's involvement in public works to their development opportunities, and did they deliberately capitalize on this? The Verachtert construction business grew out of a timber store based in Mortsel, a town on the outskirts of Antwerp, founded in 1947. Joannes Verachtert (1902–1967) started the small

Figure 2.4.5 Frans Verachtert, circa 1965.

Source: Christine Verachtert private archive.

construction company in the context of post-war reconstruction with his son Frans (1927–2005) taking his first building project in 1949 (Figure 2.4.5). Frans would take over the business during the 1950s.

The company operated mainly in the province of Antwerp and ceased to exist in 1983. Apart from a collection of index cards documenting the workforce between 1947 and 1983, the company archives were lost and as such are non-existent. The information processed in this section therefore derives mainly from two interviews undertaken with Christine Verachtert (1952), Frans's daughter (Verachtert 2022). Two lists of all completed construction works, rescued by Christine from the company archives, additionally provided information on the architect, client, cost and construction time of each project (Verachtert s.d.).

Active Building Policy and the Socialist Ideal of Living (1945–1980)

> Building, realizing: therein lies the heartbeat of a city, there one determines whether a city is alive, and how fiercely so.
>
> (Antwerpen 1952)

With these eloquent words, the City Council opened the brochure of its exhibition *Antwerpen bouwt* in 1952, which, among other things, fiercely emphasized public buildings in the city. The exhibition, organized again in 1957 and 1975 (Figure 2.4.6), was the ultimate representation of the vision of the political order that would rule the city for 30 years. Indeed, building was one of the main hallmarks of mayor Lode Craeybeckx (1897–1976), who took up office in 1947, and of his successor Frans Detiège (1909–1980). During their combined 29 years in office, then, they and their council left an indelible mark on Antwerp and its built environment. The Belgian Socialist Party (BSP) mayors' active building policy could be framed within a certain aspiration to revive the city after five years of wartime suffering. Antwerp had to be better, Antwerp had to be bigger and, above all, Antwerp had to be put back on the map as the economic heart of Flanders. This was a typical element of active government intervention in Western European

Figure 2.4.6 "Antwerpen bouwt" exhibition 1975; Mayor Lode Craeybeckx visits the exhibition.

Source: Felixarchief – Stadsarchief Antwerpen, Neg#12497.

countries of Keynesian inspiration, aimed at creating employment, social security and collective welfare (Van der Wee 1984: 26–64). These desires translated into three major political goals that had a direct impact on the city's building policy: a sound housing policy, the aspiration to be a city serving its residents and finally the economic revival of the region (Genootschap 2008: 111–113).

In terms of its housing patrimony, Antwerp faced major spatial challenges after the war. Although Antwerp was liberated by the Allies on 4 September 1944, the city was beleaguered by the dreaded V-bombs until March 1945. These weapons destroyed 13% of the total number of houses and left more than 19,000 structures badly damaged (Palinckx 2004: 135). Moreover, there had been a construction freeze during the war, which had not helped the growth of a decent and high-quality housing stock. Antwerp had a so-called housing and slum survey conducted in the first years after the war. The 1947 census showed that 20% of families were housed in overcrowded or unhealthy housing units. In the oldest neighbourhoods such as Schipperskwartier, this figure was as high as 40%. Thorough research showed that over 8% were living in so-called slums. "Conditions degrading to humans came to light", stated Jan Gaack, the then Director of Social Affairs and Housing in Antwerp (Gaack 1960: 24). For example, some 2,277 families of two and more people lived in a space consisting of only one room. In addition, some 1,300 cases were identified where 25 or more people were using one toilet (Gaack 1960: 24).

The solution to eliminate this "deficit", as the city government called it, had two components. On the one hand, the slums had to be cleaned up and, on the other, new construction had to solve the growing housing shortage (Antwerpen 1952: 1). The first part consisted of a large-scale rehabilitation operation of the ring road, with the city taking up the reins. In this way, about 5,000 slums were acquired and demolished at the city's expense (Hancke 2000: 235). New housing projects then had to be launched to replace these housing units. In 1955, the then-Health Minister Edmond Leburton (1915–1997) gave a large share of the responsibility in this area to local social housing companies, as shareholders in the city.

> If the municipalities have an important role to play in the housing problem, the task of the large building societies is already no less extensive. [. . .] Their part in the fight against unhealthy housing is of great importance, since the demolition and clearance of the unhealthy houses is closely linked to the creation of new housing.
>
> (1955: 556, translated from Dutch)

In this way, close cooperation was established between Antwerp and its social housing companies Huisvesting Antwerpen, Onze Woning and De Goede Woning. The City Council provided capital and some extensive land on the outskirts of the city to establish large-scale new housing estates. The main districts where this would take place were Luchtbal in the north of the city and the so-called World's Fair district and Kiel in the south. In exchange, the city received shares, making it the largest shareholder of all housing companies in 1952 (Gaack 1960: 26). In the north of Antwerp, in the Kiel district, this sort of development of vacant land had already started in 1950. Here, Huisvesting Antwerpen had been assigned the construction of a high-rise (socialist) "model neighbourhood", as the chief engineer of the city of Antwerp called the work. They engaged architect Renaat Braem and created a total of 800 social rental flats in two phases (1950–1958). The construction of the first phase fell to local contractors Van de Mosselaer and Frans Verachtert, who were selected by public tender (Gaack 1960: 47–48).

The execution of the first phase of the Kiel housing complex (1951–1955) was not a first experience in social housing construction for Joannes and son Frans Verachtert. From the

Figure 2.4.7 Construction of Darsen XII social housing blocks at Antwerp Luchtbal by contractor Verachtert, circa 1955.

Source: Felixarchief – Stadsarchief Antwerpen, Foto#50534.

early years of the company, there was a close cooperation with, among others, housing company Huisvesting Antwerpen and prominent architects such as Edward Craeye (1879–1958) who had specialized in social housing since the interwar period. In the Luchtbal district, for instance, 6 high-rise and 22 low-rise housing complexes were built within this partnership between 1948 and 1955 (Figure 2.4.7). The Antwerp city authorities' focus on quality (social) housing was undoubtedly a way for this contractor to strengthen their position within the local construction industry and expand their know-how through these works (Verachtert s.d.).

In terms of innovation in the construction process, the National Society for Cheap Housing and Living Quarters (NMSGG), which was closely linked to the BSP, was strongly committed to mechanization, rationalization and industrialization to reduce construction costs. The main reason for this was that at that time, the rent of a social housing unit was still calculated on the basis of total construction cost of a project. By lowering the construction cost in this way, they could give a broader stratum of the population access to the (socialist) idea of "liberated living". It would also provide them with additional capital to start new building projects. The construction of the Kiel residential complex, in particular, was an example of this approach. This so-called "experimental site" was not only large-scale, forcing the contractor to invest in equipment, but it also made an extensive use of prefabricated materials and rational site planning, which introduced the contractor to an evolution in construction methods and techniques (Angillis 2022: 39–54).

The opportunities offered by the political, economic and social situation also influenced the business operations and strategy that Verachtert NV would maintain for many years. This was reflected, for instance, in their deliberate specialization in large-scale and long-term public works roughly between 1947 and 1970 that entailed high job security (Verachtert s.d.). Mainly in the first two decades after the war, social housing construction played an important role in this. Besides their involvement in numerous small private works such as the construction of cinemas (a persistent collaboration with Antwerp architect Rie Haan, 1906–1984) and small-scale commercial buildings, there was a constant overlap with the construction of multi-year social housing projects (Verachtert s.d.). Frans Verachtert deliberately anticipated this, and it was reflected in the company's strategy. For example, while until the mid-1970s, administrative staff was very limited within the firm (five to six people), Christine Verachtert says there were three staff members who focused exclusively on tenders and winning public contracts to ensure the continuity of work (Verachtert 2022).

A Close Network of Building Actors

Besides providing decent housing, the city was also fully committed as an entity to its residents and visitors, to concerning itself with their well-being and health, and to creating a healthy economic situation with a view to further developing the welfare state. First and foremost, the port and its associated commercial activities offered the city an asset to emerge from the ruins of war. Antwerp City Council, which controlled port policy, therefore had ambitious plans for these facilities. Above all, port expansion would be high on the agenda for the following decades. This resulted, among other things, in the opening of a new petroleum port in September 1951, the inauguration of the Boudewijn lock in 1955 and the construction of the sixth harbour dock between 1960 and 1964 (Genootschap 2008: 76). It is also within these political and economic conditions that in 1949, Mayor Craeybeckx drew up his three-year plan for the creation of several important structures in the city centre. The intention was to erect three large-scale constructions that would emphasize the city's economic side (in the form of the Economic Centre, which was never built), services (Administrative Centre, 1958–1967) and social character (Seamen's House, 1951–1954) (Lombaerde et al. 2006: 76). The City Works Department (Dienst voor Stadswerken) would play a major role in this, taking on the role of client builder and caretaker. This service had come into existence in 1863, with the celebration of its 100th anniversary and its accomplished work in 1963 with another exhibition highlighting the importance of public works for the city (Rylant et al. 1964).

However, the City Works Department did not have its own architects within its ranks to take on large-scale projects, meaning that the city had to turn to private architects. It was on the advice of architect Léon Stynen (1899–1990) that some lecturers from Higher Institute of Urban Planning (Hoger Instituut voor Stedebouw) were selected as designers for these commissions. These master builders, including Renaat Braem (1910–2001), Jul De Roover (1913–2010) and Hendrik Wittockx (1893–1965), were all born, educated and raised in Antwerp, which certainly increased the interaction and connection among them and with the city. Close ties were also established with locally active contractors and city authorities, who, through repeated involvement in public works, gained confidence in their abilities (Lombaerde et al. 2006: 76). This also included far-reaching personal contacts, with Christine Verachtert testifying how, for example, architect Renaat Braem was a "friend at home" and although her father "did not share Braem's outspoken socialist beliefs", they got along perfectly on both personal and professional levels (Verachtert 2022).

A second actor that had a significant influence on the number of public works in the city was the Public Welfare Commission (Commissie van Openbare Onderstand, COO). This charity institution had been established by law in 1925, obliging local government from then on to install one "service for poverty relief" per municipality. In addition to income from real estate and donations, the COO's funds were mainly fed by grants from the municipality, the province and the state. In short, the COO's mission was threefold. On the one hand, they had to "reduce" and "prevent" the misery of needy residents, mainly in the form of housing and financial support, and on the other, they were also responsible for building up and organizing care for the sick and the elderly (Pieters 1973: 62–76). According to the 1975 exhibition *Antwerpen bouwt*, health and healthcare were "the city's most precious asset", in which the COO had a major role (Figure 2.4.8).

In the view of the Antwerp City Council, construction was about more than just erecting buildings; above all, it meant "maintaining public health and improving social services" (Stad Antwerpen 1975). In Greater Antwerp, the famous Middelheim Hospital (Figure 2.4.9) was built between 1958 and 1970, along with the Sint-Erasmus Hospital (Figure 2.4.10), designed by architect Joseph-Louis Stynen (1907–1991), the construction work for which was entrusted to Frans Verachtert.

This was not the first time that there was a collaboration between Joseph-Louis Stynen and Verachtert in this context. In the early 1960s, they had already worked together on the realization

Figure 2.4.8 "Antwerpen bouwt" exhibition 1975, model of the ambitious expansion plan of the port of Antwerp.

Source: Felixarchief – Stadsarchief Antwerpen, Neg#12484.

Figure 2.4.9 “Antwerpen bouwt” exhibition 1975, the section of the Commissie van Openbare Onderstand including a model of the Middelheim hospital.

Source: Stadsarchief Antwerpen, Neg#12531.

Figure 2.4.10 Construction of St Erasmus Hospital in the later Antwerp district of Borgerhout by contractor Verachtert, 1966.

Source: Felixarchief – Stadsarchief Antwerpen, 42#321.

of Gitschotelhof retirement home in the Antwerp district of Borgerhout, with repeated collaboration continuing in later years (Verachtert s.d.).

Incidentally, during the same period, between roughly 1960 and 1975, Verachtert NV was involved in a number of other public works that can be framed within its zeitgeist. Especially in the 1950s and 1960s, Antwerp faced city migration, and suburbanization towards its future districts such as Deurne, Schoten and Ekeren was fully in progress. Banks, among others, followed the development of these new residential centres. As such, Verachtert was assigned the construction of three branches for Belgian Public Bank ASLK (1967, 1968 and 1969) in the aforementioned districts, respectively, again in collaboration with architect Joseph-Louis Stynen (Verachtert s.d.). While the residential function in the core city thus threatened to wither away, the rise of the service economy and the important role that training and education played in it were also responsible for the changing appearance of the city.

In that context, Verachtert was involved in the construction of the large-scale Provincial Institute of Food Industry (1959–1970) and the Institute of Tropical Medicine (1971), with the province of Antwerp as client (Verachtert s.d.). Finally, in the field of social housing, a gradual shift was noticeable in Antwerp, partly as a result of a changing social perspective. The insistence on large-scale high-rise projects in the periphery such as Kiel and Luchtbal (Figure 2.4.9), where Verachtert had played an important role, gave way to revaluing the core city and low-rise social housing on a smaller scale.

The reconstruction of the sanitized century-old Vleeshuis district in the centre of Antwerp is an example of this, but the considerable expansion of the port also meant that affordable housing was in high demand in the north of the city. In that context, in the late 1960s, Frans Verachtert was assigned the construction of 130 single-family dwellings in Berendracht, a district north of Antwerp, which would also immediately be their last new-build social housing project (Verachtert s.d.).

The Crisis of the 1980s Leaves Its Mark

The relatively large number of public works in the 1960s and 1970s contrasted sharply with the unstable political situation caused by civil and social unrest (which reached its peak in May 1968), and the unfavourable economic climate that emerged with the 1973 petroleum crisis. Inflation soared, and automatic indexation also increased wages, thereby also pushing up the total construction costs of projects. However, the impact of the crisis on the construction industry and public works was delayed.

In the 1970s, for instance, the government was still investing heavily in public works, although a certain shift was noticeable towards civil engineering such as optimizing the road network, waterworks and harbour works. Government debt increased rapidly due to high inflation and interest rates. But the real crisis for the Belgian construction sector came with the outbreak of the second petroleum crisis in 1979. The number of public works on a national scale experienced a significant decline in the early 1980s, and the high cost of construction put the brakes on the expansion of social housing (Lombaerde et al. 1996: 77–147). Specifically in the Antwerp context, despite the crisis, the spatial and economic expansion of the port continued; however, investment in major urban projects stagnated. The time of megalomaniac public constructions in the city seemed to be over for good, and there was more and more focus on renovation and reallocation. Moreover, there was a tendency towards "capital city development", which emphasized a public–private partnership or a complete surrender to the private market (Van Den Broeck et al. 2015: 72).

In the field of public works, Verachtert NV's activities also underwent a certain transition. From the mid-1970s, public commissions seem to have dropped off completely, with the company focusing on small-scale private construction and renovation works in the wider surroundings of Antwerp, according to the surviving list of completed projects. On the one hand, this evolution can be linked to the unfavourable climate within the construction industry at the time, to which the company was undoubtedly exposed (Verachtert s.d.). On the other hand, however, there were also internal causes that contributed to the company's eventual shutdown during the 1980s. Frans Verachtert, who by the late 1970s was already well into his fifties and struggled with health issues, had two sons whom he initially would have liked to have engaged within the business. However, Frans junior (b. 1950) and Marc (b. 1954) chose a different path and jointly opened a shop selling building materials. Christine, Frans' daughter, though, had been working within the company as an administrative assistant since 1970. Nevertheless, a prevailing patriarchal view of Verachtert (father) on gender and business management prevented her from taking over the company. The last option, leaving the firm to a professional manager with no family ties, was also out of the question for Frans, and this left the company under threat of a rudderless future. According to daughter Christine, her father viewed the situation with a down-to-earth perspective and, especially as of the late 1970s, a so-called fading-out strategy prevailed. The workforce was thus gradually reduced, working more and more with short-term contracts and relying on "freelance" workers. In terms of its operations, towards the end, the company relied on just a few loyal foremen and office workers, business eventually coming to a modest and quiet close in 1983 (Verachtert 2022).

Reflection

The chapter first of all showed that the 19th century was an important time for the consolidation of the contractor's position in Belgium, sowing the seeds for the official recognition of the profession and title that followed shortly after the Second World War. This period also saw the foundations built for their participation in construction practice as distinct actors engaging in a varied range of tasks that would henceforth be carried out by the "general contractor" on the construction site. However, the contractor's new position within the building practice had to be both won and proven. Important elements in this consolidation process included education, with the vocational training courses at the newly established Antwerp industrial school (*Nijverheidsschool*) as a prominent example and first attempts to form modern trade associations such as the Antwerp *Cercle*.

Within these broader developments in the general contractor profession, this analysis also showed that both the national and regional and local (political) context were important determining factors. The liberalization of Belgian building practice in the 19th century, for example, gave general contractors the opportunity to take on all kinds of public works as private players and enhance not only their skills but also their status in building practice. Thus, in cities such as Antwerp, where public works were prevalent in the 19th century, early professional association initiatives arose, as cited before, and contractors were able to significantly improve their socio-economic position and influence within the urban fabric through continual contacts.

Moving into the second half of the 20th century, it was once again demonstrated how this mostly political, local context in Antwerp was an undeniably influential factor in the evolution of the general contractors involved and their activities. After the Second World War, the city's active building policy created an ideal climate through which public works contractors experienced a certain growth spurt. Here, the example of Verachtert NV illustrated how medium-sized and large public works represented an increasingly important share of their activities. The scale of the public works – such as the large-scale Luchtbal social housing project – and especially the job security and continuity attached to such works led to a conscious focus on public works as the core of the corporate strategy. Finally, examining the Verachtert case as a micro-study, it became clear how the interaction between conjunctural cycles, the number of public works and corporate strategy, and the internal structure of the company can determine the life path of these actors within the construction practice. It would therefore seem appropriate to explore these individual life paths in detail in further research if we want to fully understand the hitherto barely studied post-war construction practice in Belgium and the role of general contractors (of public works) described here.

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Chapter 2.5

Portuguese Public Works Contractors During the Estado Novo (1933–1974)

From Conjunctural Singularities to Common European Practices

João Mascarenhas-Mateus, Manuel Marques Caiado and Ivo Veiga

Introduction

This last chapter, at the end of what aspires to be a travel book on construction in Europe throughout the 19th and 20th centuries, is dedicated to the very place where the book began – Portugal – to bring full circle the various perspectives on the implantation of reinforced concrete in the country's construction culture, and in particular through major public works companies. Due to geographical location and historical trajectory, the history of construction contractors in Portugal in the 20th century has specific characteristics that were simultaneously conditioned by the multiple transformations that occurred in other European countries, ranging from the specific to the universal.

With the PTBUILDS19_20 platform, the goal of setting up different virtual exhibitions dedicated to construction history in Portugal opened up the possibility of identifying, collecting and analysing a great deal of data.[1] At the same time, the quest to establish an innovative narrative on construction history honed in on the study of an often ignored but nonetheless primordial figure that encompasses and represents all aspects of a construction culture: the building company, and in particular the public works contractor. Meanwhile, any historical study of the 20th century in Portugal must cover the Estado Novo regime, which lasted from 1933 to 1974 and radically marked contemporary Portugal over the long term. For all of these reasons, some of the most influential companies in public works infrastructures were studied as the protagonists of the historical narrative of the construction sector in Portugal during the last century.

On the platform, virtual exhibitions invite users/visitors to explore different general aspects of each company, such as the biographies of the firms' founder(s) or timelines tracking all of the known constructions works executed by that company. For each firm, more in-depth information is given for a selected number of works, connecting them with other individual actors, firms, materials, machines, propaganda and technical publications, as well as legislation (Mascarenhas-Mateus et al. 2021: 546–547). Each of the companies' construction works are also georeferenced on the world map (OpenStreetMap base layer) and classified into different types of infrastructures.[2]

The group of contractors used as case studies was chosen on the basis of their representativeness of the construction sector for the period 1933–1974 depending on their foundation date and the number of works/total sales they executed in that period. Thus, the companies analysed were (by the date of foundation): Soares da Costa (1918), Teixeira Duarte S.A. (1921), OPCA (1932), Amadeu Gaudêncio (1935), Mota and Companhia (1946), Construtora do Tâmega (1946),

DOI: 10.1201/9781003368656-15

Somague (1947), Novopca (1947), Construções Técnicas (1950), Engil (1952), Alves Ribeiro (1955), Sopol (1959) and Edifer (1966).

Data was collected from different sources: marketing and commercial publications, governmental material and propaganda printed by different state ministries, written technical studies, company budget yearly reports, wide audience and specialized periodicals, film documentaries and so on. That material was available in different formats – images, videos, graphics, diagrams and maps – and dispersed by different libraries and archives. Internal and marketing publications produced by the companies themselves were also consulted to know more about the individual history of each firm. Within this range of journal types, the *Revista Oficial do Sindicato Nacional de Construtores Civis* (ROSNCC), published between 1939 and 1976, is of particular note. The union behind the publication, founded in 1933 within the scope of the Estado Novo Constitution, presented itself as the heir of the corporation Casa dos 24 de Lisboa, which since the 14th century had been responsible for granting licenses to practice several trades, including those of mason and carpenter.

The study aimed to take into consideration different interpretations and scales for analysis of the relationships between the actors in the construction sector. On a broad scale, companies were placed in the historical, political and socio-economic context of the Estado Novo and the historical changes that occurred in building processes. On a smaller scale, the activity of the different companies was compared from different aspects: the type of construction work undertaken by each company, its location and execution date. Finally, on a smaller scale, different relationships between different companies and between companies and individual actors were drawn up, identifying their contribution to business merging or the creation of new companies.

Public Works and the Regime

During the Estado Novo period brought about by the 1926 revolutionary coup and officially established with the 1933 Constitutional Charter, public works became a fundamental instrument for the implementation of an authoritarian regime that was concerned with controlling not only the political opinion of the population but also the territory of Portugal and its colonial spaces. Thus, the fundamental Law of Economic Reconstitution (Lei da Reconstituição Económica, Decree 26.177, 1935) set aside substantial funds not only for national defence and the colonies but also for new infrastructures to develop ("foment") the European Portuguese territory. At the same time, in the context of the nationalist and totalitarian currents that flowed through much of Europe at the time, early on the regime sought out historical references that could frame the mentalities of the common citizen. To this end, the 1940 World Exhibition in Lisbon, celebrating a double centenary (the country's independence in 1140 and the restoration of independence in 1640) led to a first major campaign to build public infrastructures. This first campaign, in association with the 1935 Law – which lasted until 1948 (the 15th anniversary of the Constitutional Charter) strongly attenuated by the Second World War – had as its main objectives the construction of a network of primary and secondary schools, university buildings, collective housing quarters, prisons, a large hospital in Lisbon, restoration and reconstruction of monuments, improvement of existing sea ports and the construction of priority communication routes, the airports of Lisbon, Porto and Santa Maria (Azores).

At the end of the Second World War, three important plans destined to infrastructure in the European Portuguese territory were systematically implemented: the Plan for the National

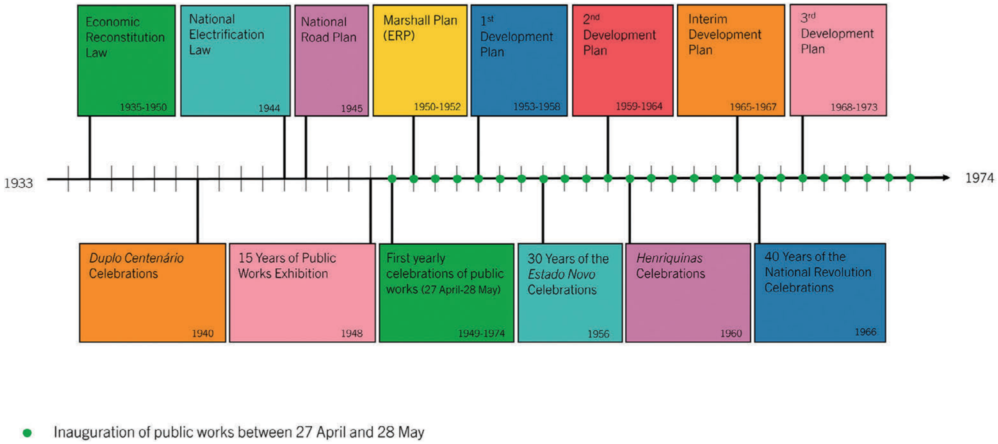

Figure 2.5.1 Representative scheme of national development plans and laws, extraordinary exhibitions and annual celebrations of the regime.

Source: The authors.

Hydric Resources (Lei dos Aproveitamentos Hidráulicos, Decree 12.559, 1926), the National Electrification Law (Lei da Eletrificação do País, Decree 2002, 1944) and the National Road Plan (Plano Rodoviário Nacional, Decree 34.593, 1945).

Having benefited from the Marshall Plan for two years (1949–1950), the regime established successive multi-annual development cycles: the first plan from 1953 to 1958; the second from 1959 to 1964 and the third from 1967 to 1973. During the first two plans, the new milestone of the Estado Novo's celebrations became 1966, dedicated to commemorating the 40th anniversary of the 1926 Revolution and to the inauguration of the new bridge over the Tagus River in Lisbon. For this reason, between 1959 and 1966, around 7,500 public works were inaugurated and listed in the "Commemorative Plan" of the Ministry of Public Works.

In association with the national development plans, a campaign of inaugurations was put into practice every year as a systematic propaganda strategy of the regime, centred on the cult of Salazar's personality. These inaugurations always took place at the same time of year: from 27 April to 28 May. The first date celebrated the day Salazar first became a member of the government, while 28 May marked the Revolution of 1926. Each year, the inaugurations of public works were listed in a catalogue organized according to district and type of infrastructure (Figure 2.5.1).

The Role of the Entrepreneur, Trade Unions and Lobbying

Until the end of the Second World War, there were very few offices dedicated solely to the design and calculation of structures for public works. Architects and engineers of recognized prestige founded their own studios, but they were a minority. Among architects, the spectrum of professionals was more varied, with important names including the Rebello de Andrade brothers (Guilherme 1891–1969 and Carlos 1887–1971), Jorge Segurado (1898–1990), Carlos Ramos (1897–1969), Luís Cristino da Silva (1896–1976), Paulino Montez (1897–1988), Porfírio Pardal Monteiro (1897–1957) and Francisco Keil do Amaral (1910–1975), to cite but a few. In the field of engineering projects, there were offices such as José Belard da Fonseca's[3]; the "Sociedade Engenheiros Reunidos" in Porto, created c. 1930; the "Laboratório de Ensaio e Estudo de Estruturas e Fundações" of the engineer Edgar Cardoso, founded in 1944 and so on. The category of designers of public works began to be constituted only in 1973, with the first congress of designers held in Lisbon and the creation in 1975 of the Portuguese Association of Designers and Consultants (Associação Portuguesa de Projectistas e Consultores – APPC).

During the Estado Novo, in practice, the design and approval of many of the improvement projects funded by government schemes for large-scale expenditure were mostly done by the engineers and architects of the government institutions themselves and directorates of the Ministry of Public Works (MOP). Only a portion of the projects were executed by private engineering and architectural firms on the basis of a public tender or by invitation.

As for the execution itself, the works were usually awarded to the construction company offering the lowest bid. Until 1967, public works procurement procedures continued to be regulated by a law dating from the monarchy (Ordinance 4 October 1897) with very few changes. Under this regulation, almost any public contractor could submit a bid for any type of public work. In 1939, Decree-Law 29.931 of 15 September started to require that civil constructors carried a professional card to exercise their profession. Despite this requirement, which implied prior training at a technical or industrial school, there was still no distinction between specialities or the types of infrastructure that each civil constructor could apply to build.

This situation began to change in 1950 and 1952 with the creation of two new builders' associations – AICCOPN: Associação dos Industriais da Construção Civil e Obras Públicas in Porto and the AECOPS: Associação de Empresas de Construção e Obras Públicas e Serviços in Lisbon – which replaced the Northern and Southern guilds founded in 1890 and 1892. Since their foundation, almost all the 13 contractors selected for this study were represented on the executive boards of those two associations. With AECOPS and AICCOPN, the contractors' lobbying of government led to the institutionalization of a new national code (Decree 40.623, 1956) followed by an ordinance (Portaria 18475, 1961) that classified all contractors into seven categories: (1) civil construction works, (2) hydraulic works, (3) bridges, (4) roads and airports, (5) urbanization works, (6) electrical and mechanical installations and (7) foundations. These categories were subdivided in different technical specialities such as special foundation works, metallic structures, reinforced and prestressed concrete works, maritime works, airports, bridges and dams. In each association, the acceptance of applications for membership was thus decided based on the basis of a prior assessment of the technical and material capacity of the applicant company to execute each category of work. In 1967, lobbying by the two associations was equally successful in drafting additional regulation: the new procurement code for public contracts with price revision clauses (Decree 47.495, 1967) and the regulation on construction in the private sector. In 1973, Decree-Law 73/73 of 28 February made it possible for civil builders with diplomas from industrial and technical schools to be responsible for the design of buildings up to a maximum of four storeys and a total floor area of 800 m^2. The decree also authorized qualified civil engineers to design simple structures and common technical installations. With this diploma, civil builders were placed on a par with architects and engineers who designed buildings and current works. However, the diploma was suppressed after the 1974 Revolution (Figure 2.5.2).

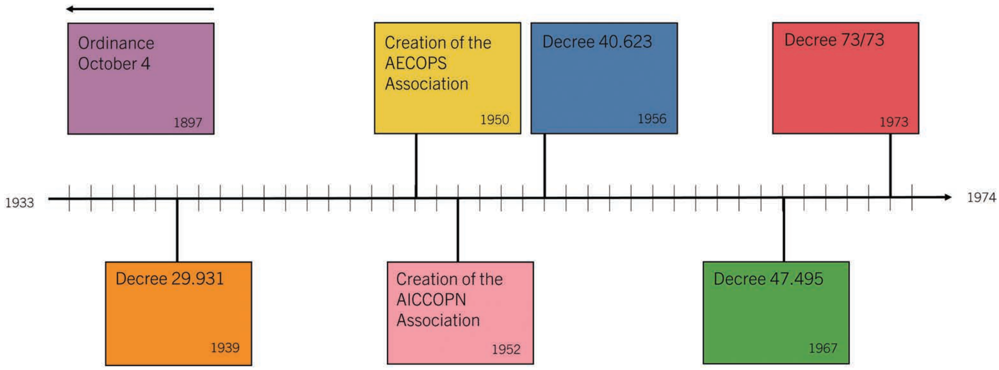

Figure 2.5.2 Creation of professional associations and main laws regulating public works.

Source: The authors.

Entrepreneurial Growth and the Importance of Human Relations

Having described the context of the institutional figure of the public works contractor, it is possible to move on and study their relationships with other individual actors (builders, architects and engineers) and collective actors (companies and institutions) for a deeper analysis of a network of actors which, at first sight, would seem disconnected and fragmented. First, different professional and personal relationships within the construction sector were identified. The protectionist and interventionist policy of the regime, *Condicionamento Industrial* (Industrial Conditioning), restricted the execution of major public works to a limited group of actors through the nature of the procurement selection process. In fact, most of the industrial incentives created by the government ended up boosting the growth of economic groups from already well-established companies and the creation of very few new groups.

Numerous examples of family dynamics in the founding and expansion of these companies can be found, together with the converging interests of professionals who had begun to collaborate on common projects. Family-based configurations were quite common when companies were created. Most of the companies studied had a specific family name as their majority shareholder: Mota (Mota & Companhia), Fonseca (Construtora do Tâmega), Moniz da Maia (MSF), Alves Ribeiro and Teixeira Duarte in their homonymous companies, Vaz Guedes (Somague) and the Pires Coelho family for Edifer.

The existence of family ties would be fundamental to the evolution of these companies, and this translated into the relationships between actors within and between the companies (Figure 2.5.3). In this respect, we should start with the Teixeira Duarte, Moniz da Maia and Vaz Guedes families. Ricardo Esquível Teixeira Duarte (1886–1959) and Bernardo Ernesto Moniz da Maia (1900–1988), 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 his brother, Ernesto da Cunha Moniz da Maia. The two cousins and José Vaz Guedes (1902–) started by founding a construction company called Sociedade de Empreitadas Moniz da Maia, Duarte & Vaz Guedes. José Vaz Guedes had already built the first stretch of motorway in Portugal with concrete pavement between Lisbon and the National Stadium (similar to the German *Reichsautobahnen*) with Bernardo in 1944. However, disputes over the order of the names in the company's brand name put an end to this project and took the cousins in different directions. Ricardo continued with his company Teixeira Duarte, founded in 1921, while Bernardo created the company Moniz da Maia & Vaz Guedes (later called Somague) in 1947 with his longstanding friend and colleague José Vaz Guedes. As a sign of their excellent relations with the regime, the works for the Castelo de Bode Dam were immediately commissioned to the newly founded company in that same year.

Another case of fruitful family relationships concerns the Mota and Fonseca families, and the two companies that would later become major economic groups. The relationship began with the marriage of Manuel António da Mota (1913–1995) and Maria Amália Guedes Queiroz de Vasconcelos (1925–2004) in 1946. From that moment onwards, the Mota and Fonseca families became involved in a strategic alliance which would see Manuel and Joaquim Fonseca (his brother-in-law) join forces to set up Construtora do Tâmega a year later. The new company would operate in mainland Portugal, while Mota & Companhia concentrated its activities in Angola. Once again, the two families would eventually go their separate ways: in the 1960s, the Mota family remained 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 mainly observed in the initial years of each company, these links extended to actors belonging to different professions or to both the public and private sectors. In the first case, OPCA is the most evident example. This company, founded in 1932, undertook works of great importance at an early date, especially in the city of Porto. The joint venture between the two brothers Manuel (civil engineer, 1919–1989) and Januário Godinho (architect, 1910–1990) contributed strongly to the company's public image, including in its portfolio innovative reinforced concrete buildings such as the Garagem Sentieiro car park (1932) and the Fish Market in Massarelos (1933). In the second type of relationships, the names of Ricardo Teixeira Duarte and José Vaz Guedes and António Valadas Fernandes (engineer and founder of Engil, 1927–2009) stand out. All three men were simultaneously business owners and members of the Estado Novo's Corporate Chamber in different legislatures, ensuring their presence in both the public and private 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 (Figure 2.5.3).

Despite the importance of family and professional ties, other types of relations must also be taken into consideration: the relationships between construction companies. These are particularly interesting at founding moments. Amadeu Gaudêncio (1890–1980) was one of the founders of Sopol in 1959, while OPCA was one of the founding shareholders of Novopca in 1947, a company that operated until the 25 April 1974 Revolution as a branch of OPCA.

The peak of these tight corporate networks would only be reached decades after the end of the Estado Novo, at the end of the millennium, when several acquisitions and mergers between major companies took place. For example, the merger of Engil and Mota & Companhia led to the creation of one of the largest public works conglomerates in Europe.

All these considerations reinforce the idea that the Estado Novo was, for the construction sector, a period with "a high degree of concentration", especially in relation to industrial and financial groups.

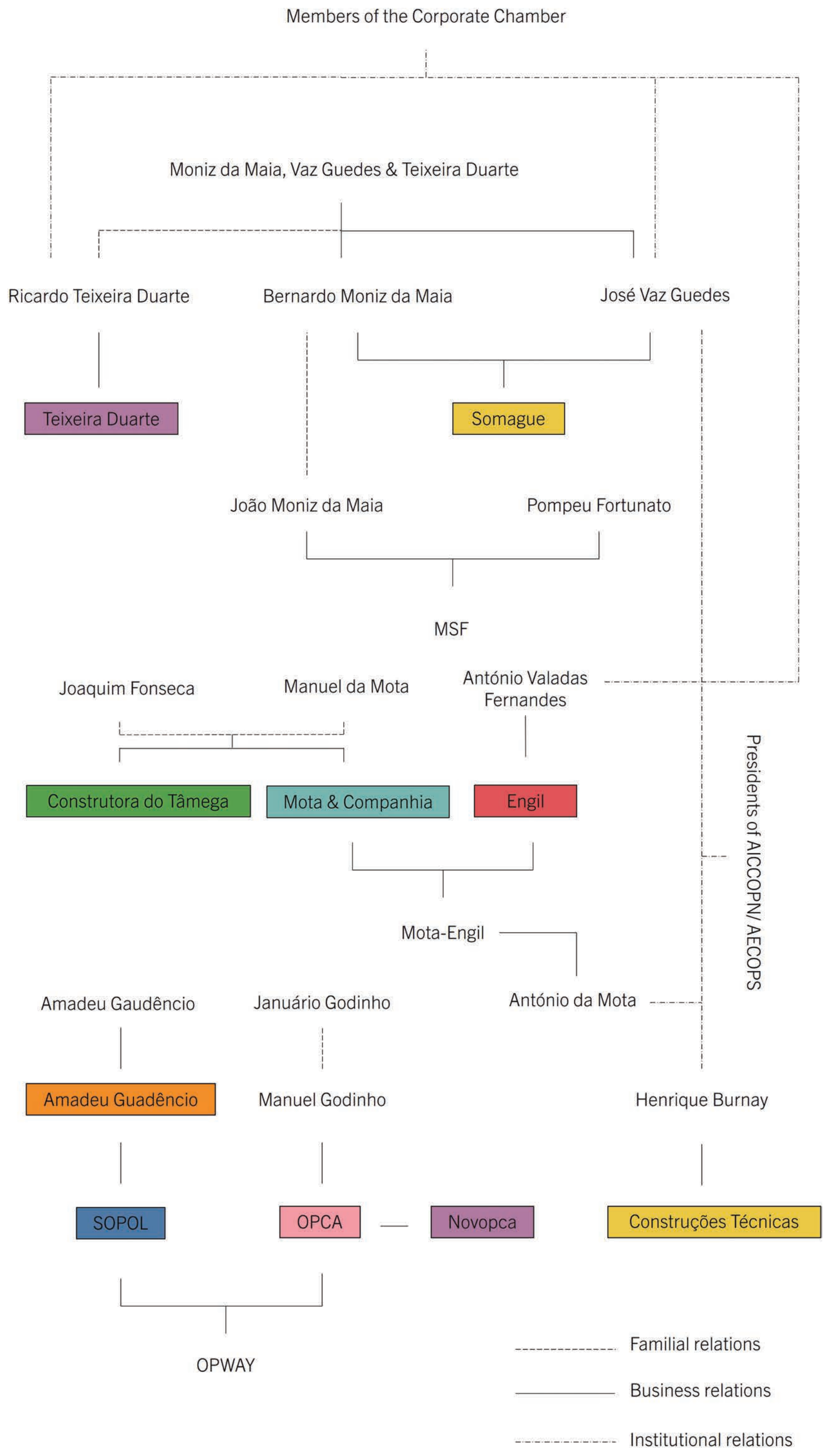

Figure 2.5.3 Family, professional and institutional relationships between the company's founders.

Source: The authors.

Public Infrastructures and Construction Companies

Considering the political and economic context and the main family dynamics in the creation and merger of the companies under analysis, a comparative analysis of their activity was carried out on the basis of the works identified during the preparation of the two virtual exhibitions on the PTBUILDS digital platform.

The construction works were classified into 25 different categories or types after combining different infrastructure classifications that would best summarize the 375 works under analysis (Torrisi 2009), namely: dams, power supply, water supply, railways, landscaping, bridges, roads, airports, ports, transportation, housing, communications, religious, administration, defence, industry, health, education, research, justice, tourism, commerce, monuments, sports, recreation, waste. From the typological analysis, three main trends could be extrapolated.

First, it was possible to find 11 companies that have executed works belonging to at least seven different construction typologies. OPCA and Engil carried out works classified in 16 and 12 types, respectively. Six companies show a balanced distribution of projects by type: Edifer, Soares da Costa, Teixeira Duarte (Figure 2.5.4), Alves Ribeiro, Sopol and OPCA. Looking at Edifer and Teixeira Duarte, the number of works performed under the most frequent types – housing and water supply, respectively – does not exceed the percentage of works performed under any other type in the company's portfolio by more than 22%. This confirms the marked versatility of a considerable number of companies.

As a second trend, a set of companies was identified, whose portfolio has a significant number of works focused on a limited number of types. This is the case of Amadeu Gaudêncio, Construtora do Tâmega, Construções Técnicas, Engil, Mota & Companhia and Novopca. For Amadeu Gaudêncio (Figure 2.5.5), works linked to services (health, commerce, recreation, education and tourism) constitute approximately 36% of the whole portfolio. In the case of Construtora do Tâmega, airports represent about 40% of the works, while in the case of Construções Técnicas, 44% fall into the industry category. Mota & Companhia and Novopca are two extreme cases: airports and bridges account for more than half of their portfolio – 64% and 53%, respectively.

A third group of companies can be classified not only into a single typological category but also into a group of related typologies. For example, the works carried out in the "Transport" area (roads, railways, airports, bridges) by Mota & Companhia (Figure 2.5.6), Novopca and Constructora do Tâmega correspond to 73%, 58% and 55% of their total portfolio, respectively.

But the activity of these construction companies could also be analysed from a geographical perspective. As for the location of the works, most were 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 Setúbal district, part of the Lisbon metropolitan area, and the Faro district, an urban and economic hub and tourist centre since the 1960s, these works account for 60% of the overall portfolio. Lisbon is responsible for more than 25% of the portfolio of most companies: Novopca (36%), Engil (33%), Construções Técnicas (39%), Teixeira Duarte (50%), Sopol (50%), Alves Ribeiro (74%), Edifer (88%) and Amadeu Gaudêncio 80%). In the Porto metropolitan area, this asymmetry is particularly remarkable, with OPCA and Soares da Costa being responsible for 31% and 73% of the works completed in this area. These results demonstrate how the historical structural conditions of regional and "coastal" asymmetry of economic activities also influenced the construction sector and, unsurprisingly, the companies selected for this project.

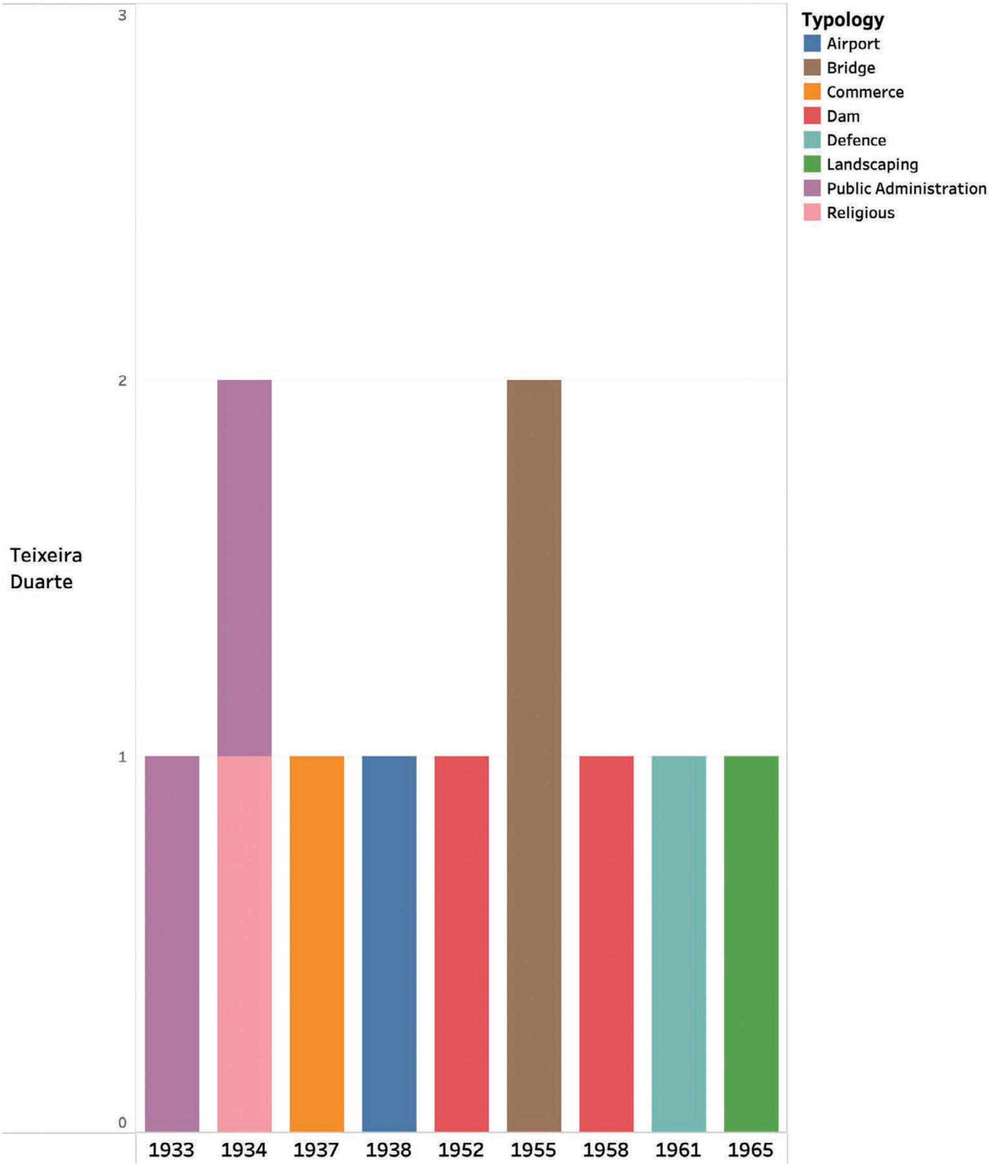

Figure 2.5.4 Distribution over time of the types of constructions executed by the company Teixeira Duarte.

Source: The authors.

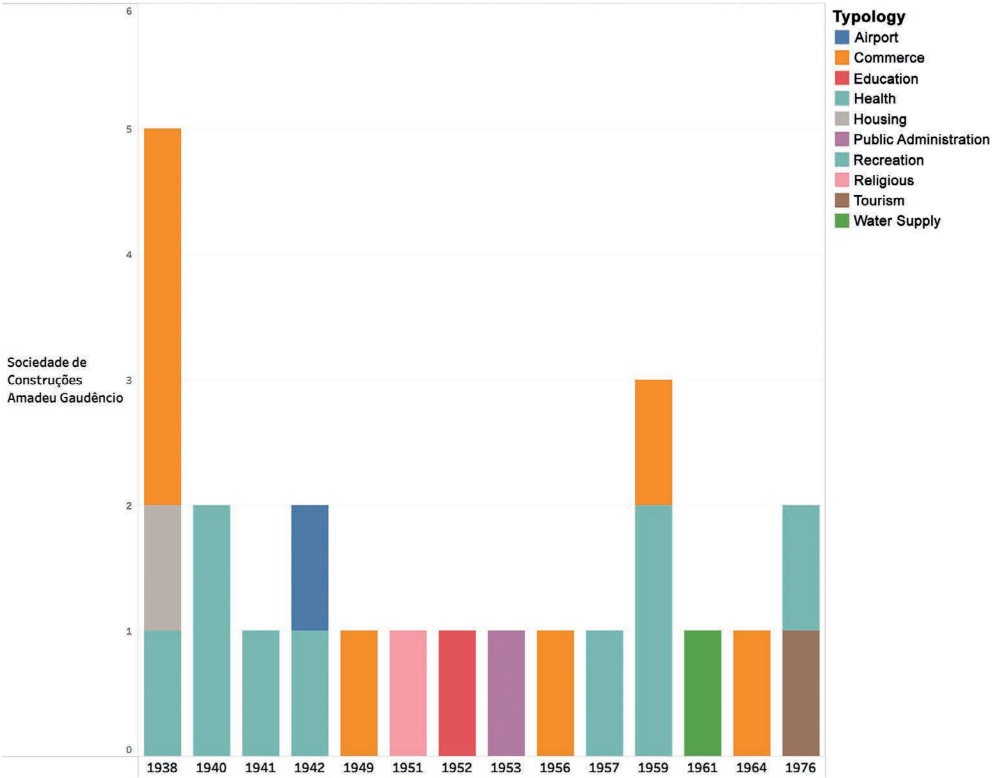

Figure 2.5.5 Distribution over time of construction typologies executed by Sociedade de Construções Amadeu Gaudêncio.

Source: The authors.

Outside the European mainland, some singularities can be found in the geographical activity of Portuguese companies. For example, Construtora do Tâmega concentrated around 20% of its operations in Madeira and the Azores. In others, as in the case of Mota & Companhia, efforts in airport construction are mainly in Portuguese-speaking territories such as Angola.

When the analysis is applied to the constructions carried out by each of the companies individually, it is also possible to identify the categories of works most frequently carried out in a given geographical area (Figure 2.5.7).

A substantial proportion of the achievements of Alves Ribeiro, for instance, are in the Lisbon area in the category's airports, roads and sports. Similarly, Amadeu Gaudêncio concentrates

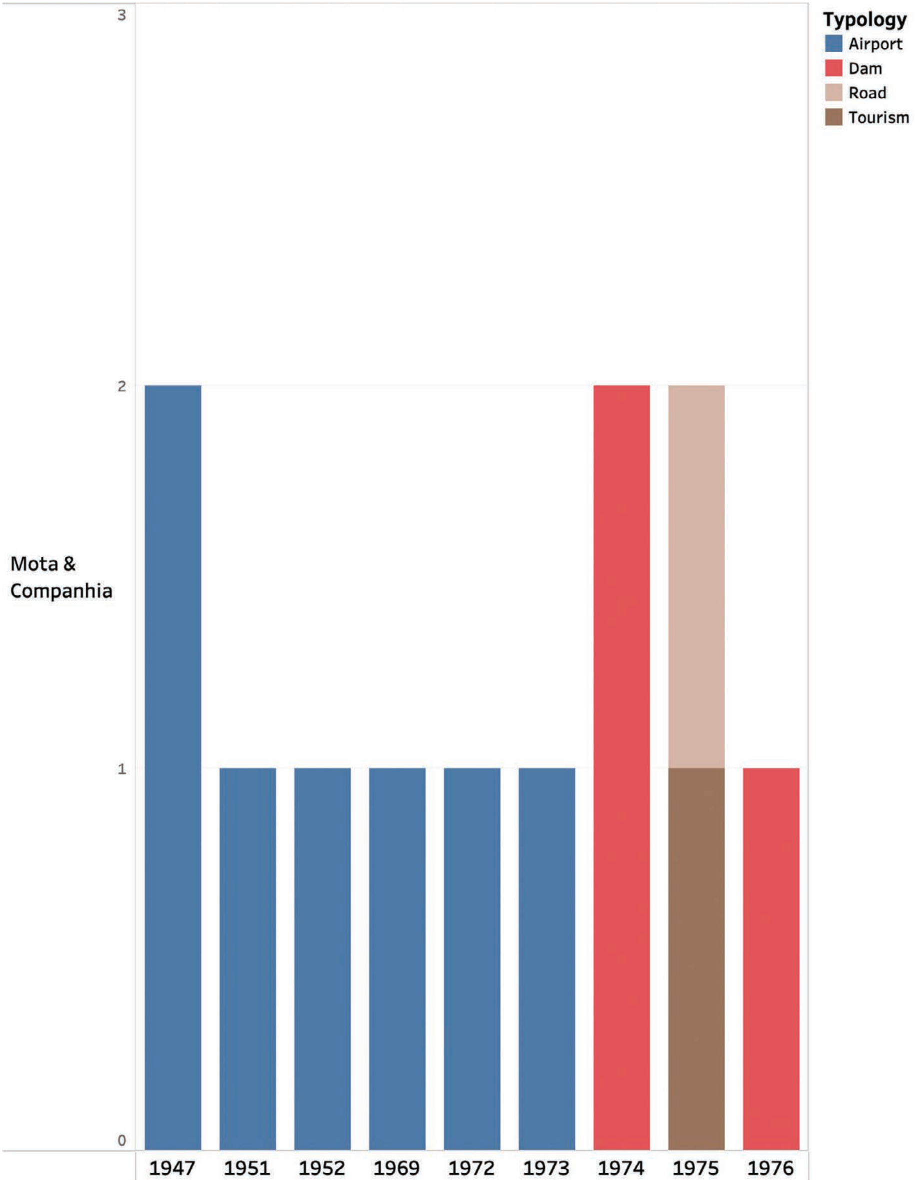

Figure 2.5.6 Distribution over time of the types of constructions executed by Mota & Companhia.

Source: The authors.

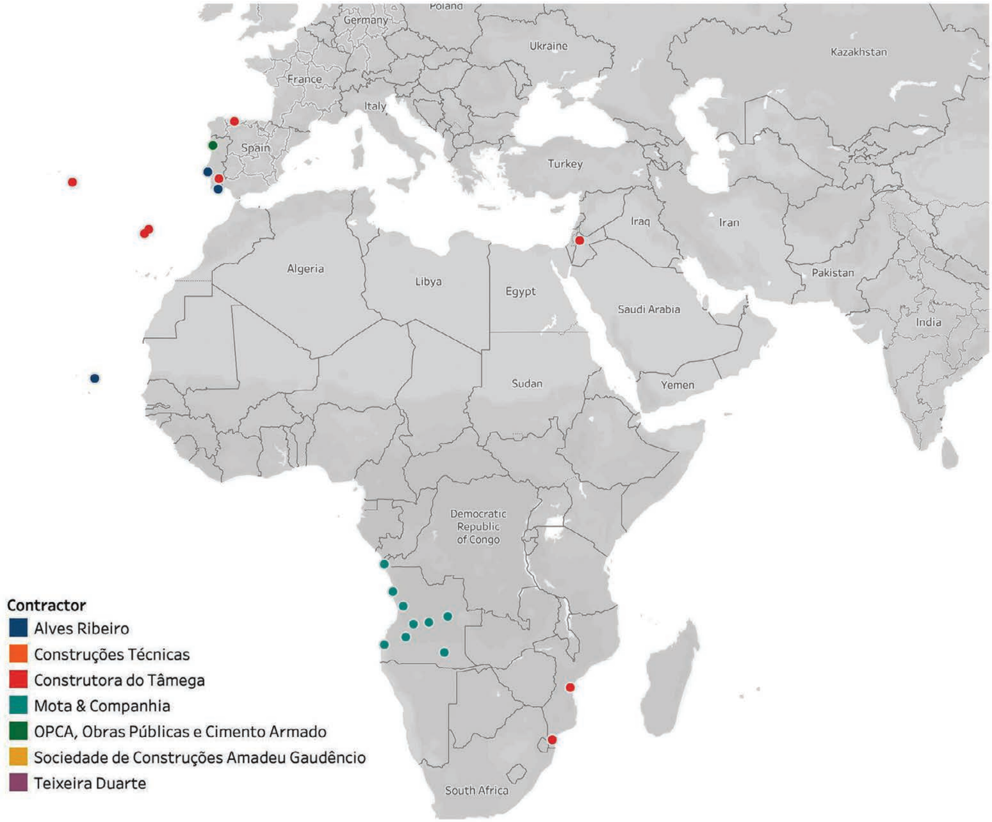

Figure 2.5.7 Geographical distribution of the airports run by the companies analysed.

Source: The authors.

most of its activity in Lisbon, in the commerce category. In contrast, works classified under health and recreation are scattered throughout the country. Novopca stands out in the bridges category for a significant number of districts. Meanwhile, Construções Técnicas is characterized both by an intense activity in Lisbon and by various projects in the former Portuguese colonies, namely in ports and industry.

To conclude this comparative analysis, a temporal analysis explains the response of these companies to the different historical situations (Figure 2.5.8). In fact, four key moments in the history of public works can be identified: (1) the period 1938–1940 and the Portuguese World Exhibition; (2) the years of the Second World War when, despite its position of neutrality, Portugal experienced a decline in the construction sector; (3) the period 1959–1971 with the peak in the 1966 celebrations and (4) the period of rising production costs beginning in 1971 and accentuated with the 1973 oil crisis, which marked the last years of the Estado Novo.

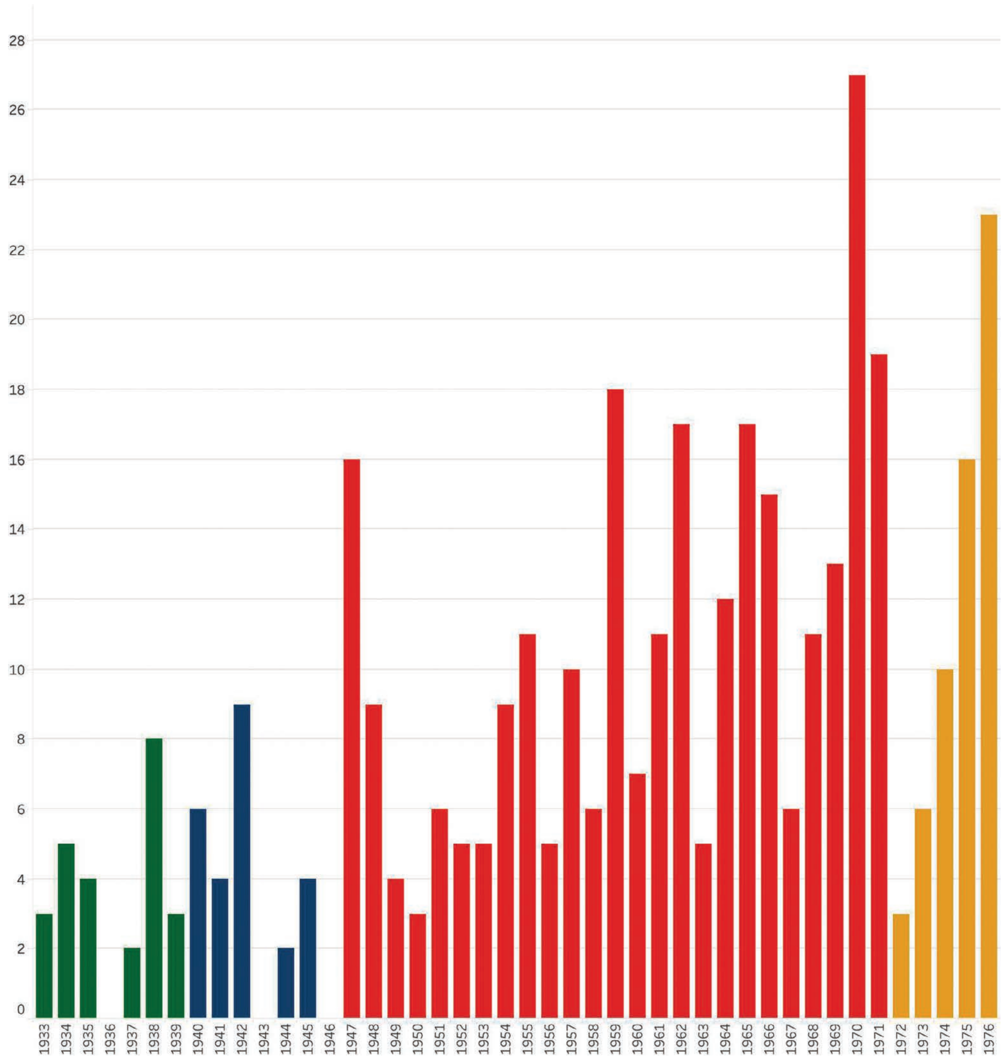

Figure 2.5.8 Yearly construction works by the 13 companies. In green: prior to WWII; blue: WWII years; red: postwar period before the First Oil Crisis; yellow: First Oil Crisis years.

Source: The authors.

Contractors, Building Processes, Machinery and Materials

Public contractor companies in Portugal were thus rather confined by bureaucratized public procurement and corporate control of their business. These political and economic constraints help to explain the transformations that occurred in the construction processes used by the selected companies during the Estado Novo period. In fact, consulting the list of works executed by the 13 companies yields a history of the evolution of reinforced concrete in Portuguese construction culture. Under the Reinforced Concrete Regulation – the national code published in 1935 that replaced the first code of 1918 – the different development plans used concrete in a very pragmatic, economic and rational way, considering the availability of materials and the percentage of newly trained engineers in the calculation of structures. In reality, reinforced concrete was only included in the engineers' curricula by the Government Decree no. 2103 of 1915, which created the course on Reinforced Concrete at the Faculty of Engineering of Porto, held for the first time in 1919–1920 (Rodrigues 1920). In 1918, it was the turn of the Instituto Comercial e Industrial de Lisboa (Decree 5029, 1918) to establish a course like the one in Porto.

Thus, reinforced concrete started to be used mainly in complex structural infrastructures with important span lengths, special foundations, high strength and durability qualities, such as bridges, reservoirs, dams, hydraulic works, docks, airport runways, industrial facilities and important building structures, including public markets, banks, hospitals, stadiums, ministries, prisons, cinemas and theatres. In housing, until the 1950s, reticulated reinforced concrete structures were mainly applied to solve spaces with larger spans and cantilevered façade elements in conjunction with traditional masonry walls. Relevant examples are the Massarelos refrigerated fish warehouse and the Fish Market building in Porto with a 10-m high porticoed structure and 20-m span beams executed by OPCA (1933–1935), the new porticoed façade of the Assembly of the Republic founded on in-situ foundry piles (Teixeira Duarte 1933–1942), the Arroios-Lisbon market (Amadeu Gaudêncio 1938–1942) or the huge new hospital in Lisboa-Santa Maria, a nine-storey building with an area of 128,000 m^2 (Amadeu Gaudêncio, 1940–1952). In all these types of buildings, the widest opening in the façades was usually closed with metal windows made of laminated glass. This new, cheaper and more reliable industrial material was easily available from 1941, thanks to the new glass factory Covina, created after the forced merger of the seven older factories that produced glass by manual methods.

The limited use of reinforced concrete was determined by a self-sufficient and state-protected domestic Portland cement market, fed by seven major factories opened consecutively in mainland European Portugal: Alhandra (1894), Outão (1906), Maceira-Lis (1923), Pataias (1949), Cabo Mondego (1950), Cisul-Loulé (1973) and Cinorte-Souselas (1974). But in contrast to the growing importance of the cement industry, Portugal was for a long time dependent on steel imports. The import monopoly held by only a few companies was only broken in 1961 with the creation of a national steelworks company in Seixal with a capacity for 250,000 tonnes/year of rolled products, of which 150,000 tonnes/year of rebar for the construction sector (Pereira 2003: 1,188). The increasing demand for the two reinforced concrete primary products was mainly determined by the growth of the public construction sector, with the private sector accounting for only a residual part of the consumption of Portland cement and rebar.

But it was only at the end of the Second World War, with the 1944 National Electrification Law, the 1945 National Road Plan and the creation of successive development plans, that public works achieved a more stable and continuous growth. In this context, priority was given to the fields of electrification and irrigation (dams, hydraulic works, hydroelectric and thermoelectric plants). For all these installations, the technological improvements offered by reinforced concrete were highly appreciated. From the beginning, Somague built several cylindrical arch dams: Alto Ceira (1949), Castelo de Bode (1951) and Odiáxere (1958). This was followed by double-curvature arch dams: Cabril (Somague, 1954), Bouçã (OPCA, 1955), Picote (OPCA, 1958) and Varosa (Somague, 1972–1976). Many concrete gravity dams were also built, several by the companies under analysis: Bemposta (Somague, 1964), 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 widely used for the first time in the development of the Bairro de Alvalade

(OPCA, 1947) and replicated throughout the country in large buildings such as the São João Hospital in Porto, built with cellular concrete blocks in 1949.

Just before the Second World War, pavement systems with precast beams obtained with the assembly of hollow bricks[4] were first disseminated. In 1935, the magazine *A Arquitectura Portuguesa Cerâmica e Edificação Reunidas* advertised the "viga nacional" (national beam) (Figure 2.5.9), prefabricated with reinforced hollow bricks, produced by the company SIMCO (Lisbon & Porto) under Portuguese patent no. 17.462.[5]

After the war, the ROSNCC published a series of articles from 1946 by Eng. Ameixa on a greater variety of block and beam floor systems based on hollow bricks and also with reinforced cellular concrete blocks. This is the case of the Sistema Celular Perfeito of hollow bricks (Portuguese patent no. 20357) licensed to the company Fassio Lda, from Lisbon and the Pavimento Isolador Rosacometta system from Milan, Italy, with cellular concrete blocks produced in Portugal by Sociedade Rosacometta do Norte (Figure 2.5.10). In the same magazine, new systems with prefabricated reinforced concrete beams appeared such as the Corfeho system, from March 1950. In 1951, the brand Patial,[6] from the Sociedade Industrial de Pavimentos de Tijolo Armado, Lda, began marketing prestressed precast joists. In 1953, patent no. 24.930 was announced for a block and beam floor system and, in the same year, the Pressito system of prestressed concrete

Figure 2.5.9 The "viga nacional" (national beam) advertised by SIMCO and produced under Portuguese patent no. 17.462.

Source: A Arquitectura Portuguesa Cerâmica e Edificacao Reunidas, no. 2, May 1935.

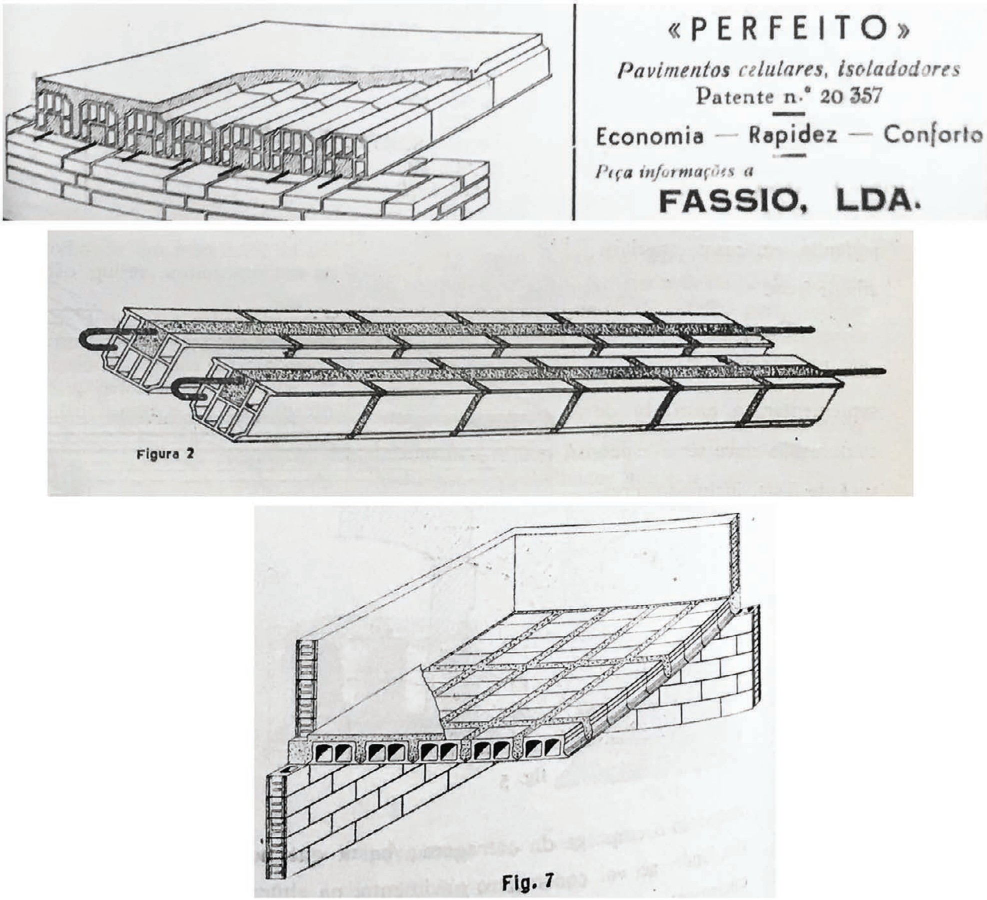

Figure 2.5.10 Top: two images of the "Sistema Celular Perfeito". Bottom: detail of the "Pavimento Isolador Rosacometta".

Source: Ameixa (1950: 2015, 1946a: 1166, 1946b: 1259).

for large spans. In 1958, Freyssinet patents Precomat (Porto) and Novobra pavements (Lisbon) from Sociedade de Pré-Fabricação e Obras Gerais, Lda were advertised. In 1962, these producers were joined by the company Vibrapaque from Porto.

Besides the use of prefabricated beams to quickly build pavements in current buildings, for large pavilions, the use of reinforced concrete shells became a common solution, such as the parabolic hangar reinforced by a grid of arches (40-m span, 16 m high, 98 m long) for the Industrial Association in Lisbon (Construções Técnicas, 1952–1955) or the 25-m diameter dome for the Lisbon Planetarium (Novopca, 1964).

In the category of bridges, the most common solution for medium spans (20–40 m) until the 1960s used continuous girder bridges with beams monolithically cast with the deck; for longer spans, many open-arch deck arch bridges were built. An example of the former solution is the Vale da Ursa bridge in Tomar (spans 9 × 30 m, Somague, 1949–1951). An example of the latter is the bridge over the river Sousa, a 115-m span and 14.8-m high open parabolic arch bridge built by Novopca in 1950–1952 and advertised by the company as the longest reinforced concrete arch bridge in Portugal at the time (Figure 2.5.11). After the first prestressed concrete bridge built in 1954 (Vala Nova, Benavente, three single beams with 36-m span), the new construction method became commonly used in increasing span lengths. Shortly afterwards, an arch bridge with a prestressed deck (47-m span) was built in Sacavém (Construções Técnicas, 1957).

Figure 2.5.11 Parabolic arch bridge over the Sousa River, design by Edgar Cardoso, inaugurated during a yearly celebration of the National Revolution. Construction and advertisement by Novopca.

Source: *A Indústria Portuguesa* magazine, no. 291, June 1952: IX.

Some years later, Sopol managed to build the 945-m long access viaduct to the metallic suspension bridge over the Tagus River in Lisbon, a segmental box-type prestressed reinforced concrete bridge built by cantilever (38.0-m maximum span) on double columns with a maximum height of 64.0 m, the longest suspension bridge in Europe at the time (MOP 1966).

Some other emblematic works included Luanda Airport in Angola (built by Mota & Companhia in 1954), the Cristo Rei monument in Almada to thank God for having saved Portugal from the Second World War (82 m high, reinforced concrete porticoed pedestal topped by a 28-m statue of Christ, OPCA, 1959), the Sacavém viaduct on the A1 highway (reinforced concrete driven piles, 1 m diameter, 50 m deep, Construções Técnicas, 1959), the Boeing 747 hangar in the Lisbon airport (Construções Técnicas, 1971) or the Cabora Bassa dam in Mozambique under construction in 1974.

In addition to the emblematic constructions that incorporated the most advanced solutions for resolving major engineering problems, the construction companies also kept up with developments in machinery, equipment and construction materials in current use.

As far as foundation systems are concerned, the whole historical period under analysis reflects the successive application of piling systems inspired by the Franki system and some competition between contractors to control their representation in the country. Thus, already in 1932, the company José Arnaux from Porto offered the Franki piling system in the ROSNCC (Figure 2.5.12). Two years later, OPCA published a photograph of a load test on Franki piles used in the Faculty of Engineering of the University of Porto. In 1934, Teixeira Duarte also announced

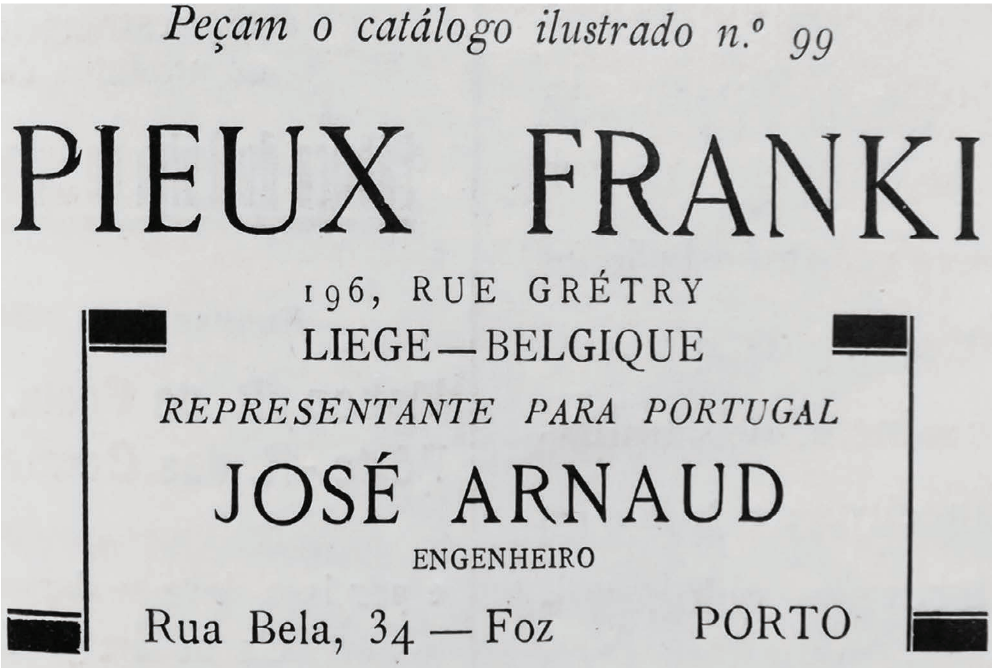

Figure 2.5.12 Franki piling system advertisement, 1932.

Source: Revista da Associação dos Engenheiros Civis Portugueses, no 686, August 1932.

the use of the system in the works of the National Assembly Palace in São Bento in 1933, Casa da Moeda and Nossa Senhora de Fátima Church both in that same year, in Lisbon. The Rhodium system began to be sold in 1945 by Valtér Weyermann (Lisbon), and the first advertisements for the Benoto system were published in the ROSNCC in 1962, together with the Delmag setting machine from 1967.

With regard to machinery, it is important to highlight first the gradual transformation of the power supply system of the many digging, moving and lifting machines that had been available since the end of the 19th century and had been improved before the Second World War. After the war, most machines were powered by petrol and diesel but continued to be imported, given the restrictions on commercial products produced in Portugal, despite the existence of metal-working factories engaged in the production of railway carriages and locomotives (Sorefame as of 1943), material for the electrification network (Efacec, 1948) or car assembly (Salvador Caetano, 1961). For cranes, steam systems (Besnard brand) were advertised in the 1930s, being marketed by the company Marcelino Pelayo (Lisbon) from 1948 onwards, diesel systems on caterpillar-tracked trains or on car trains with tyres and Caterpillar brand revolving towers. Diesel-powered excavators came on the market mainly from the 1960s, with brands such as Bristol-Saunders and Harvester, always represented by Portuguese companies such as Fassio and Lda. Jaw and compound crushers, as well as concrete mixers and pneumatic hammers, were also marketed by Marcelino Pelayo from 1948. For roads, vibratory rollers for compacting pavements of the Stothert & Pitt brand were also marketed from 1948 by E. Pinto Basto & Companhia Lda.

Alongside specialization in certain types of public works, the position of a company as the exclusive national licensee of an international construction system patent also helped to increase competitiveness. This was the case with Construções Técnicas and Engil, for example. Each company had the right to use a different slipform for casting processes for high-rise structures on site: Construções Técnicas for the Prometo slipform (AB Bygging) from 1953 (Figure 2.5.13) and Engil for Siemcrete (Siemens-Baunnion) from 1969. As a result, in 1969, Construções Técnicas could 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 high buildings' core and piles of Tourém Bridge (1970–1972), with a cast-in-place deck supported by precast cantilevered prestressed concrete beams.

Apart from the transformations observed in the power supply systems of the large machines required on a construction site, new equipment appeared in association with reinforced concrete technology, in addition to the Prometo and Siemens-Baunnion sliding formwork systems. The petrol/diesel and electric pneumatic vibrators of the Wacker and Vibro-verken brands, designed for concreting large volumes and surfaces, should be mentioned here. They began to be marketed in Portugal as of 1948 (Figure 2.5.14) by SOGERE, Sociedade Geral de Representações Lda (Lisbon/Oporto) and later by others such as Marcelino Pelayo (Lisbon), Empreitadas de Fernando CCR Teixeira (Lisbon), SIMET (Lisbon) and Rolim Comercial (Lisbon).

The technological improvements after the Second World War are also evident in the field of temporary structures. From 1958 onwards, ROSNCC frequently advertised the French Tube & Coupler scaffolding system created in 1939 by Mills, licensed to the Portuguese firm Rebel. In the same year, the Mundus scaffolding system from Portuguesa Estruturas Metálicas (Lisbon), used in the construction of the Christ the King Monument in Almada, was also advertised (Figure 2.5.15).

Figure 2.5.13 Construções Técnicas advertisement for the Prometo system and the Benoto pilling system.

Source: Revista Oficial do Sindicato Nacional dos Construtores Civis, no. 241, May 1960, p. 8,484.

Figure 2.5.14 One of the first concrete vibrators advertised in Portugal at the end of an article by Eng. Ruy Henriques da Silva published in 1948.

Source: Silva 1948: 1,625.

Figure 2.5.15 Advertisement for the Mundus scaffolding system, 1958.

Source: Revista da Associação dos Engenheiros Civis Portugueses, no. 222, October 1958, s/n.

As far as materials are concerned, ROSNCC advertises products made only with Portuguese raw materials such as aerated and hydraulic lime, Portland cement, solid bricks, hydraulic mosaics, cork panels,[7] resins and derivatives, fibrocement,[8] laminated glass and glass blocks.[9] As previously mentioned, Portugal only started to have a real steel rolling mill in 1961 with the creation of the Siderurgia Nacional. Therefore, all iron and steel products for construction were imported and transformed in Portugal. In this case, we should mention the Oliva factory, founded in 1925 in S. João da Madeira, which started producing galvanized steel pipes and cast-iron radiator tubes for central heating systems in the 1940s, or the Companhia Portuguesa de Trefilaria SARL (founded in 1947), which began to provide most of the Portuguese production of reinforced bars for reinforced concrete.

However, in addition to these materials, the Estado Novo period saw the successive appearance on the market of materials such as Plexiglas (with adverts from Dynamite Actien Gesellschaft – Röhm & Haas, GMBH as of 1955), aluminium window frames (Sonorte, 1958) or bituminous emulsions with the brand Estancol or the one produced by the petroleum company Shell under the Flintkote brand, for reinforced concrete surface coatings, from dam walls to flat building roofs (commercialized as of 1948). There were also thermal insulation materials such as diatomite (marketed from 1952) and vermiculite, as of 1961.

Conclusion

In 1974, the year of the Revolution that put an end to Salazar's regime, many new public and civilian contractors were members of the builders' associations of the north and the south of the country. Prestressed concrete was a common solution for many types of structures; prefabrication was present in all construction processes. The 25 April Revolution and integration in the European Union would deeply change the volume, procurement process, geography and actors involved in public works in Portugal. However, the conformation of the large contractor network remained in part because the policies and the "way of doing things" of the State regarding public works were indelibly marked by the policies of the Estado Novo regime.

This document reflects only the results of the interpretation of the archival material gathered to build two virtual exhibitions intended to give a panoptic view of the history of construction in Portugal with a digital platform. However, it demonstrates the great potential that big data analysis can have for the study of the business fabric in the construction sector of a country like Portugal. For an exhaustive study of the issues at stake in the contractors' activity, other companies – active during that period, also responsible for emblematic construction works and with large companies – should be studied to refine the accuracy of the results.

As with the history of the implantation of concrete construction culture, the history of contractors can be taken as a starting point for the study of the history of construction in the 20th century: a valid "pretext" for studying the major transformations of European construction cultures.

Construction companies, so little studied in history in general, reveal themselves to be rich actors because they were and are constant transmitters and recipients of forms of construction that have to adapt to the markets of materials, to the techniques capable of optimizing processes, to the training of their staff, to the forms of project conception and to the great socio-political and economic conjunctures of the country where they operate and of the world in general. Just like a tile from a panel of tiles with an elaborate, busy design, the study of construction companies is an indispensable element to gaining a deeper knowledge of the broader, complex world of the European building cultures of the past and of today.

Acknowledgements

This research was funded by the FCT – Fundação para a Ciência e Tecnologia research project, reference no. PTDC/ARTDAQ/28984/2017.

Notes

1 Like a former study presented at the Seventh International Congress on Construction History – 7ICCH (Mascarenhas-Mateus et al. 2021), this chapter is based mainly on the results obtained from the data gathered by the open-access digital platform PTBUILDS19_20 available in www.portugalbuilds.org (Mascarenhas-Mateus & Veiga 2020). The PTBUILDS19_20 platform uses "Omeka" as its main tool, a content management system widely known in digital humanities to publish online exhibitions and collections based on digital units called items. The PTBUILDS19_20 platform is organized in four main collections: Individual Actors, Collective Actors, Concrete Objects and Abstract Objects.
2 The 25 typologies used are: 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.
3 Belard da Fonseca (1889–1969), technical director of SETH – Sociedade de Empreitadas e Trabalhos Hidráulicos (created by the Danish company Højgaard & Schultz in 1933) was, from 1934 onwards, the representative of the construction companies as proxy to the Corporate Chamber, the legislative advisory body of the regime.
4 These systems are based on Italian patents developed from Sigismondo Ghilardi's first patent in 1902, the so-called *solai laterocementizi* (Pagliuca 2016: 195–276).
5 From 1946 onwards, ROSNCC advertises the same patent marketed by CEL – Construções Especiais, Lda (Lisbon).
6 From the 1970s onwards, the *Patial* brand no longer mentions the number of the Portuguese patent but instead states that it is the "Stahlton Patent", that is the Swiss system Stalton (Stahlton) for blocks and beams.
7 During this period, the factories producing main cork insulating panels and cork claddings were Mundet & Cia. of Spanish origin, with a factory in Portugal since 1905 in Seixal, and Robinson Bros. Lda, with a factory in Portalegre that began producing cork stoppers in 1848.
8 Asbestos cement products (pipes for water supply and sewage, slabs for roofs, tanks to which prefabricated houses were added from 1939 onwards) are produced at the Lusalite factory in Oeiras, owned by Raúl Abecassis, from 1933 onwards. In 1942, Cimianto was created with a factory in Alhandra and Novinco was created with a factory in Leça do Balio in 1946.
9 The first advertisements for glass building bricks and mosaics, produced by Covina, appear in the RCSS beginning in 1970.

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