Computational thinking in design and fabrication for augmented and accessible museums

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Abstract

The attention to the universal accessibility of spaces and culture is rapidly growing, and both computational thinking and emerging technologies are fostering the proliferation of innovative strategies and processes, from design to management, to facilitate the inclusiveness of museum spaces and the dissemination of cultural heritage.

In this context, starting from the small scale of museum devices and installations, computational design strategies, new digital fabrication technologies and advanced multimedia narratives are gaining ground in the design-research and original development of immersive and rewarding inclusive experiences.

Our research work on this subject started in 2019, tackling the design and prototyping of an accessible device for the multimedia and tactile exploration of pictorial works for people with visual impairments. The brief had the potential to tackle the historic debate on the concept of the frame, a debate based on a visual fruition of the artworks that totally loses its value from the perspective of a visually impaired person. A new question emerged: Can we reformulate the role of the frame and envision a new model that encourages alternative cognitive processes and facilitates the tactile exploration of pictorial artworks?

Lately, in 2021, ALO was commissioned the design and prototyping of a larger multisensory and accessible installation for the Lazzaretto Cultural Art Centre in Cagliari, the Digital Story Explorer. The DSE was originally conceived as an adaptable system to tell the story of historic buildings, cities and territories through a hybrid multisensory narrative strategy, physical, digital and tactile at the same time.

The search for a strategic combination of advanced design, digital fabrication techniques and uncommon building materials (such as composite materials) carried out so far has led to identifying both current critical issues and potential directions for rethinking the role of museum exhibition devices as nodal to the creation of accessible cultural spaces of immersion for active involvement of visitors. Through a sample of projects realised within ALO's current architectural practice, the paper will illustrate this ongoing design research on contemporary strategies, processes and new materiality aimed at an accessible and experiential museality.

Author keywords

Accessible museums, Digital fabrication, Craftmanship, Smart cities, Digital

Introduction

In the field of design research on accessible spaces and culture, starting from the small scale of museum devices and exhibition systems to the full scale of museum buildings, computational design and digital fabrication technologies together with advanced multimedia strategies have a special potential to engage visitors in inclusive, immersive and rewarding experiences. From the designers' point of view, one of the most significant aspects of a direct access to digital fabrication technologies is the ease and speed of in-house prototyping and self-production of final designs. A significant added value is given by the ability to produce complex solutions not feasible with traditional manufacturing techniques. This allow to deliver fully customized projects that are strictly adhered to the specific content, design scenarios and physical spaces which are all ever different case by case, as well as to implement specific strategies to address accessibility requirements and target visitors for a social but more individual experience.

In this sense, conventional products and exhibition systems and space design can no longer provide a fully contemporary experience, so that the visitor is not a passive spectator, but an active agent of the narrative(Hall, 1987). Hereby emerges the need for new strategies based on the integration of multisensory storytelling to intercept the expectations of visitors who are becoming, most of them unconsciously, increasingly demanding due to the ubiquitous exposure to multimedia, sensing, interactions, interconnections and automations that are pervading all spheres of human life(Bekele et al., 2018). In this sense, advanced design techniques and digital fabrication, understood as inextricably intertwined constituents of a holistic thinking, take on a new value. Design innovation and non-serial production become critical towards creating inclusive and experiential landscapes for visitors' engagement.

Then, furniture, podiums and content display elements might acquire a new role and design dignity as means of communication and involvement of the public in a physical and architectural experience. If we no longer simply observe, but we are forced to move by the experience(Manning, 2012), museum spaces can become landscapes for active immersion. Hence, from a utilitarian approach, which started leading the design of museum spaces and displays starting in the XX century (Desvallées & Mairesse, 2010), we might shift to the design of immersive museum installations to encourage a complete multisensory experience of contents.

This article will showcase two projects (Aptica and DSE) framing our R&D agenda and take on the subject from a design studio practice point of view.

Our research agenda on this subject started in 2019, thanks to the collaboration with CRS4, Sardinia's Centre for Research, Development and Advanced Studies, which commissioned ALO the design and prototyping of a functional device for the multimedia and tactile exploration of pictorial works. Lately, in 2022, we completed the development of the DSE, an accessible storytelling system to tell the histories of historical buildings, cities, and territories that has been commissioned by the Lazzaretto Art Cultural Centre in Cagliari.

The DSE represents a new milestone as it provided the opportunity to deepen our research with respect to the conception of exhibition systems as agents to trigger a physical and multisensory experience of cultural content.

Aptica. A multisensory interface for museum accessibility

Our work stems from the initial studies developed by CRS4 researchers as part of the 'Over the View' research project. CRS4 initiated the development of software and hardware infrastructure to transform pictorial works of art into scaled 3D representations suitable for tactile exploration. The simplified miniatures were to be equipped with sensors to enable the playback of multimedia content describing the area being touched. Hence, ALO prototyped a new complete and functional physical interface called APTICA (fig.1), which gave he systems the integrity of a complete and finished product.

Figure 1. The APTICA interface with 3D miniature of the artwork. The touch feelers sensing surfaces enable the multimedia tactile navigation of contents.

Accessibility by design

Museum experiences and art exhibitions are undergoing a transformation(Allen & MInnion, 2020): from passive viewing of exhibitions and exhibits, there is a shift to entirely new ways of offering imaginative tours that stimulate viewers and offer accessible, rewarding and memorable experiences. As summarised by A. Marras (Mameli et al., 2021), museum accessibility emerges at the intersection of physical aspects of museum spaces and displays with cognitive, sensory, cultural, economic and digital aspects.

Zooming on the process of tactile experiences from a practical point of view, it requires training and preparation(Galati, 1996); this was a critical observation that emerged also during the meetings with the CRS4 research team including Andrea Ferrero, a visually impaired researcher and artist; as Ferrero pointed out, a strategy is needed to see objects with the hand. From the perspective of a designer, there are certain drive criteria that should be taken into consideration in order to facilitate the process of tactile recognition and achieve the most effective results (Levi & Rolli, 1994).

In this regard, in addition to the relevant utilitarian aspects, the brief from CRS4 showed the possibility of opening a new chapter within philosophical, historical and semiological discussions about the frame, an object that has so far assumed the status of a theoretical object as observed by Pinotti (2018) (Daniela Ferrari & Pinotti, 2018). Pinotti illustrates the story of the frame, which appeared in a context that intended art as a reality detached from the one we live in. The frame was a boundary between the representation and real space which purpose ranged from intensifying the perception of the depth of the field or projecting the movement outwards.

The historical evolution of the role of the frame went through various phases until its denial. However, the whole debate starts from the assumption of a visual fruition of the artworks; therefore for people with severe visual impairment, the frame in its traditional conception loses its value. This raised a new question: Can we reformulate the role of the frame and imagine a new model that perhaps supports alternative cognitive processes and facilitates a tactile exploration of pictorial artworks?

Moving from the concept of the frame as a boundary for the eye to that of an intensifier of the senses was a critical challenge of the project. For this purpose, the research agenda explored the design of an interface that would serve to prepare the hands for the tactile experience.

Preparing for the tactile exploration

Figure 2. Global view of Aptica interfcace.

Aptica was designed as a tabletop object which body seems floating over the supporting surface. The aim was to isolate it from the surrounding physical world and stimulate the perception of a suspended, autonomous object on which to focus one's senses.

Following the instructions of a tour guide, the first part a visitor should come into contact with is the perimeter of Aptica: a fragmented edge consisting of a sequence of thin ribs that point towards the centre of the 3D touch tablet. The fragmentation aims to provide an initial intense tactile transition from the surrounding solid objects to the sensory space. (fig.2)

Then the hands meet the skin: a continuous and smooth surface that finishes the top of Aptica body and surrounds the tactile tablets. It is a neutral transition zone intended to evoke new feelings in contrast to the previous one to familiarise the touch with a smooth and continuous surface. The goal is to prepare the touch for the perception of three-dimensional figures which edges are necessarily more complex. The concave shape of the skin guides the hands towards its deepest part, suggesting an immersion into the sensory space of the 3D miniature. To achieve a smooth and sturdy surface, the skin was made of composite material and cast in a mould fabricated at ALO's workshop by CNC robot milling.

Finally, at the centre of the skin there is a platform featuring a set of spring-loaded electrical connectors ready to plug the interchangeable tactile tablets (fig.3). These are automatically recognised by the system via an embedded RFID card that recalls the respective audio and video descriptions. All software and system data are stored on a PC in a technical compartment integrated into the body of the Aptica. (fig.3a)

The tactile tablets are produced according to the subjects to be represented. On the top of each figure there is the touch feeler, a sensing inductive surface consisting of a sophisticated design that is generated through a computational process to meet project brief requirements.

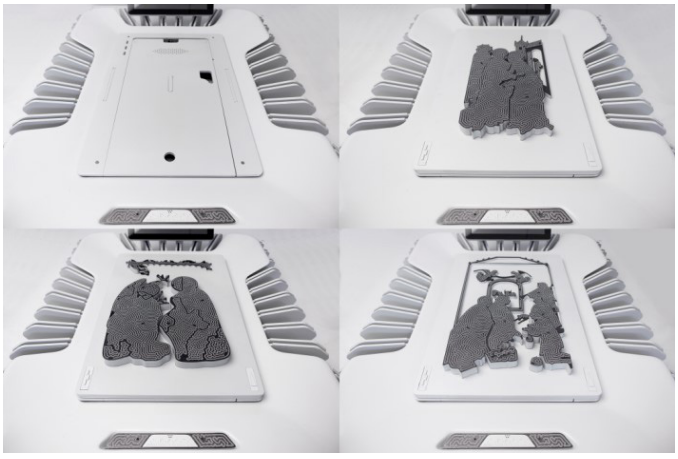

Figure 3. The APTICA interface features a technical compartment (3a) and it is designed to host interchangeable 3D tactile boards that can be swapped without the need for any technical intervention.

The computational design of single line touch feelers

As illustrated by L. Lanzi (Mameli et al., 2021), the realisation of the prototype involved a preliminary careful study of the artworks selected for the project from an iconographic point of view, with the consequent choice of the main elements to be reproduced and arranged as 3D figures of different height, so as to make them easier to read through touch. This initial work was carried out by CRS4 research team and experts involved in the Over the view project.

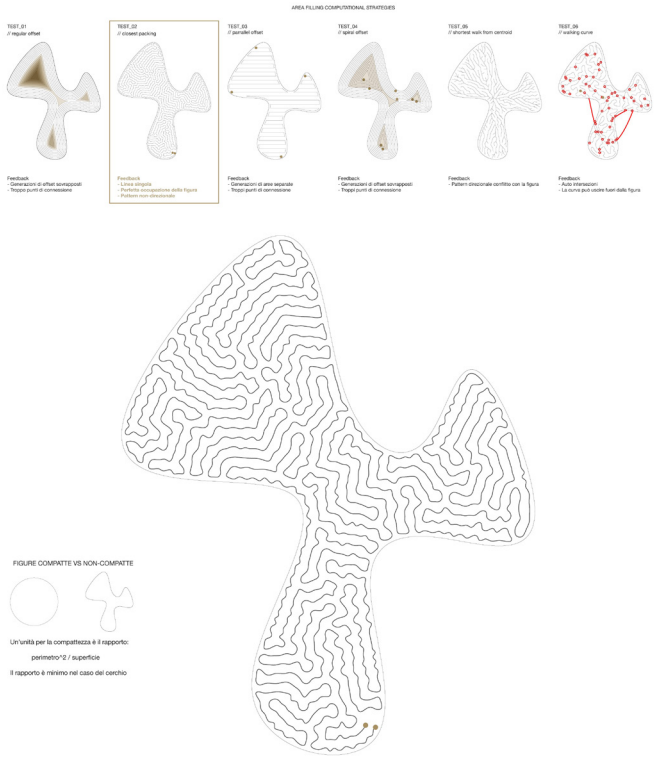

Figure 4. On the top a catalogue of attempts for a single-line filled surface with the points for electrical connection. The diagram on the bottom shows a final sample generated by the computational process.

The top-layer of each figure has been developed as a sensing surface, the touch feeler, which perceives visitor's touch and activate an audio narrative dedicated to the user, also with the possibility of asking specific questions. The development of the touch feelers was the second major design-research topic indeed.

ALO was asked to develop a sensing system based on two electrical connections (positive and ground) that would work without bracelets or additional connections involving the user. The main goal was to finds a system that could adapt to every kind of figure with minimum amount of electrical connections. Various geometric approaches were explored (fig. 4) to design conductive traces that could even detect the touch of a single finger anywhere on the surface of the figure.

However, in the case of non-compact figures, most of them failed to produce single-curve occupancy, which was very important in order to avoid over-complicated wiring and ensure system stability and scalability. Moreover a non-directional pattern appeared to be beneficial to avoid confusing the tactile exploration. Hence, we decided to investigate a computational method to generate an occupation pattern consisting of a single curve filling any kind geometric figure, compact or non-compact.

The studies of D. Hilbert or W. Sierpinski on space-filling curves(Sagan, 2013) showed a possible way forward, so we researched a computational protocol that, starting from a given boundary condition (the edge of the figure) and a set of genotypic parameters and constraints, modulates and folds

back the edge on itself up to fully occupy the figure with a single complex curve.

Figure 5. Detail of the conductive graphite pattern of the touch feelers prototype.

Through this procedure, which combines physical-computing methodologies and parametric-associative design strategies, we obtained a generative system that fills the space of the figure, while still matching production and functional constraints. The graphite based touch feelers were then prototyped in our laboratory by fine-tuning a fabrication protocol combining painting, cutting and laser engraving as to achieve repeatable and stable results.

Aptica prototype has proven the viability of the solutions researched and developed. Moreover, as the entire object and all its part has been designed as a parametric system, it is adaptable to every artwork, independently of shape and size and it is ready for immediate digital fabrication with basic CNC machinery.

Digital Story Explorer (DSE). Digital technologies for museum accessibility

The Digital Story Explorer (DSE) is the prototype of a multisensory museum accessibility system designed to tell the story of historic architecture, cities and territories in a contemporary, immersive and accessible way. In its first implementation (DSE 1.0), the system was customised for the permanent exhibition "Lazzaretto ieri e oggi" (open at the Lazzaretto in Cagliari since 13/2022) curated by the Cooperativa Sant'Elia 2003, to tell to tell the story of the Lazzaretto in Cagliari (Italy) and the life of doctors, quarantined, and people hosted and working in the building at the time of the plague (1830).

The DSE project continues the design-research undertaken during the Aptica project and the design of the tactile and interactive models of the Genna Maria and Serri Nuragic archaeological sites (also developed as part of CRS4's Over the View project in 2020) toward the larger scale of the exhibition space and its constituent elements.

Thanks to a renewed design and production approach, the agenda aims to establish a deeper relationship with the specificity of the exhibition spaces and content, and even the display podiums and structures acquire a pivotal role in the experience. Design research thus expands from the field of museum devices to that of immersive spaces, intending to amplify and awaken the sensory engagement of visitors by combining the very architecture of installations with more exploratory and trans-modal storytelling.

Hereby, digital design and fabrication techniques, including 3D printing and robotic fabrication processes, become strategic to personalize museum experiences by perfectly adapting them to the content and exhibition spaces and offering rewarding one-off experiences.

Design for all. A matter of form at the intersection of space and media.

The agenda is to blur the boundaries between the visitor's senses through the very materiality of exhibition elements and multimedia. The very design of the exhibition architecture and its constituent elements, such as display podiums, can play a central role in creating an inclusive and immersive atmosphere, in establishing immediate engagement with visitors, evoking feelings of curiosity and encouraging them to imagine themselves in other times and places, guiding them in a subtle manner through an active experience of the contents. (Waern & Løvlie, 2022)

The DSE 1.0 provides that the narrative about the Lazzaretto is unfolded through the support of a scale model. The structure of the building was reproduced following the plans of the 1830 from Alberti stored at the State Archive of Cagliari. However, telling non-experts the story of a building as a whole, its internal organization and life, with a static model is particularly limiting. Therefore, the challenge was to build a fine dynamic model with a hidden mechanical system. Finally, the ground floor opens up by sliding under the first floor according to the visitor's actions on the graphic navigation interface.

The entire 3D model was optimized for 3D printing with photo polymeric resin combining transparent resins for the facades and roofs and opaque ones for the structures and interior partitions to maximize the final efficacy. In addition, a dynamic lighting system accompanies the exploration by following visitor's actions down to the interior of the individual rooms which story is told. The rooms themselves come to life through the reproduction of animations from the graphic novel "Bartolomeo Salazar, the Last Plague Doctor," created by artist Stefano Obino, which are played back on the display of the navigation station and the wall in front of the DSE accompanied by a narrator's voice telling the story of those spaces among historical facts and memories passed down from generation to generation.

An advanced design of exhibition devices can provide new opportunities for a more immersive and pleasant cultural dissemination. With this goal, the podium displaying the dynamic model and the trans-modal navigation station (fig.6) were designed as a single entity. Even though they are two separate objects, their spatial relationship and shape are inextricably entwined (fig.7).

The design of the two elements pays special attention to younger visitors and those with visual and physical impairments. The intersection of their needs was made possible by an integrated parametric design approach that relays on a non-serial production approach to digital fabrication. This synthesis, guided by a humanistic approach to technology, helps to fulfil multiple requirements through formal articulation.

The wooden structure of the podium prevents the youngest and most exuberant visitors from touching the moving 3D-printed parts, while it also favours total enjoyment from above and below. It was also a deliberate decision to eliminate

Figure 6. Close-up view of the transmodal navigation interface with touch displays and touches tablets representing the two floors of the Lazaretto building with built-in touch sensors.

any protective cover to avoid barriers between visitors and the main subject of the narrative. As an alternative, an integrated sensor system activates an acoustic alarm signal to warn visitors in case of need.

The navigation station features a touch screen and an integrated tactile interface, consisting of two 3D-printed tablets representing the plans of the two-storey building and incorporating sensors for navigation. Finally, both the screen and the sensors, in a complementary manner, activate both the navigation through a 3D digital simulation of the building, the dynamics of the physical scale model and the multimedia content related to each room explored by the visitor.

The supporting structure of the navigation station is especially dedicated to wheelchair users, who can use the monitor or touch tablets (fig.6) while maintaining almost total visibility of the model and the rooms in which the narrative takes place without having to move.

The DSE features an embedded custom-made brain taking care of its behaviour. DSE mechatronics, both software and hardware, was custom-made by ALO team to allow communication between the digital graphic navigation system, touch screen, sensors and the physical model, controlling at the same time the synchronized payback of all multimedia contents, the dynamic lighting and the actuation system the makes the ground floor of the model opening to show the interior structure. All graphic effects, animations and lighting behaviours are generated through code and executed by an integrated mini-pc; the control engineering relays on the open-source Arduino platform to allow maximum flexibility and adaptability of the system to future, unexpected developments.

3D printing and digital fabrication for museum accessibility

Providing a contemporary and rewarding experience is perhaps one of the challenges with the most significant impact on the material and construction aspects of an exhibition, its structures and devices and, at a larger scale, on the museum space itself. In this regard, Digital fabrication fosters the realisation of effective interventions that require, by their very nature, unconventional and deeply customized solutions(Scopigno et al., 2015).

Only a few years ago, neither Aptica nor DSE would have been feasible with the same final quality as well as in a reasonable time and cost-effective manner.

Today, thanks to the democratisation of digital fabrication processes, coupled with the research-oriented approach that characterises ALO's transdisciplinary agenda on non-serial production, the basic research, design and prototyping phases come together to address accessibility with innovative solutions quickly and with reliable results, starting with clean and functional details such as those of touch tablets (fig.6) with embedded sensors.(Dellantonio, 1993).

For the DSE, in particular, all the technologies directly accessible at the ALO laboratory were strategically combined: the wooden display structures were manufactured using six-axis robotic milling, as was the complex 3D mould for the fibreglass finishes of the upper part of the podium. All the parts of Lazaretto's dynamic model, on the other hand, were produced by large-scale stereolithographic 3D printing allowing high quality and fine details. Finally, DSE 1.0 is a prototype but has all the characteristics of a finished product.

Conclusion

Digital technologies for design, production and interaction are proving to be excellent instruments for high-impact storytelling and dissemination of cultural heritage. Perhaps, for an inclusive and emotional engagement, technology alone is not enough.

Figure 7. The podium with the 3D printed dynamic model and the navigation station

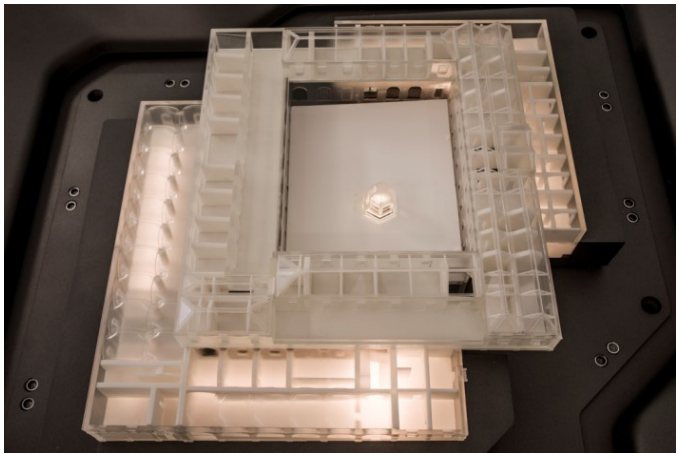

Figure 8. View of the ground and first floor of the 3D printed dynamic model. Ground floor lighting is on as this is the floor currently selected for the exploration.

Rather, it seems that it is particularly necessary to adopt technology from a humanistic and creative perspective as much as to engage with a holistic, interdisciplinary practice to rethink museums' space and equipment design.
The search for novel strategies and modalities to establish more dynamic and evoking connections between visitors and contents might pass by the materiality itself of the display elements and spaces and the embedded digital technologies as a whole.

Both Aptica and DSE are an applied and functioning expression of an original take on the subject by addressing design and production as inextricably interwoven aspects. The two projects proceed from an interdisciplinary approach whereby computation, matter and fabrication actively merge in the pursuit of a physical and emotional involvement of visitors, as to prompt them to move and explore contents and museum space as a whole, with curiosity and in a more personal and intimate way.

Hence, devices and exhibition infrastructure are no longer solely intended to be functional furniture to display content, but they are conceived as agents themselves for a complete, accessible and satisfying experience. These take on a new role with a significant dignity that requires renewed design intensity. Hereby, they become suggestive subjects of research and expression for practitioners to address universal accessibility and the design of rewarding experiences beyond already acquainted models.

Acknowledgments

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