

Review: design reshape the relationship between museum collections and visitors in digital age

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With the development of digital technology, it has become common to use modern computing and interactive technologies to enhance communication between people, physical spaces and digital information. Most museums are also beginning to apply the new technology of the day to improve the experience of the visitors. The relationship between museum collections and the audiences they serve has been reshaped through design. Design has become a key tool in the museum and cultural heritage sector with the advent of the digital age. This review summarises three trends in exhibition design in the digital age through a combing of the literature: multi-sensory, immersive and non-linear narratives. It also extracts from the literature the frameworks of exhibition design in the digital age: the exploratory framework and the application framework. And presents the research trends under the framework.

Keywords: *museum digitalization; design; visitors; review*

1 Introduction

The "museum modernisation movement", which began in the late 19th century, led to the emergence of the social function of museums. However, for the most part, museums are still perceived as places where collections are displayed (Yang&Pan,2005). In the middle to end of the 20th century, the New Museology movement led to a further and continuing shift in the concept of the museum. The starting point of the New Museology movement was the Round Table of Santiago in 1972 and the Declaration of Santiago de Chile. However, the new museology was not recognised by the international museological community until 1985, when the Movement Internationale pour la Nouvelle Muséologie (MINOM) was founded. Peter van Mensch(1992), on the basis of the statutes of the MINOM, summarises the New Museology in four characteristics: it allows people to better understand their own existence; it takes into account people in their natural, social and cultural environment through an interdisciplinary approach in which the concepts of milieu and context are essential; its methods and practices are used to promote the participation of the inhabitants; and it has a flexible and decentralised structure. Sharon Macdonald (2006) summarises it in the following three points: that



the meaning of museum objects is not fixed but varies according to context; a renewed focus on matters previously considered outside the field of museology, such as commerce and entertainment; and an understanding of how museums and exhibitions are perceived and related to by visitors, and an understanding of the museum visit from an audience/public perspective.

The New Museology has caused traditional museums to re-think. Under the pressure of the new paradigm, traditional museums have begun to adapt and revise themselves, including but not limited to the construction of information and meaning beyond the collection itself and the attempt to work from the perspective of the public. Museums are beginning to realise that collections not only have the value of material evidence and objective truth, but also, and more importantly, that they carry with them collective consciousness and social attributes. Elaine Gurian's(1999) understanding of museum collections is illuminating: "If the essence of a museum is not to be found in its objects, then where? I propose that the answer is in being a place that stores memories and presents and organizes meaning in some sensory form." Thus, at the level of designing museum displays, the interrelationships between collections and social issues outside the museum become the primary focus for museums in developing exhibitions. In the new museology, the importance of the visitor is re-evaluated. The public perspective of museums means that their work begins to centre around the interests, values and satisfaction of their audiences. Zahava Doering (1999) described the evolution of the treatment of visitors to museums in terms of a developmental sequence from stranger to guest to client. Academic research on museum audiences is also growing (Kathleen, 2003; Calvin, 2006). Despite there is a saying that the current shift from 'object-centred' to 'visitor-centred' museology (MacDonald & Alsford,1991; Schweibenz, 1998; Greenhill, 2000), the fact is that the debate on 'object-human relations' in museology has never ended.

Outside the museological community, the ongoing development of technology has also intensified the self-adaptation and shifting of museums. With the development of digital technology, it has become common to use modern computing and interactive technologies to enhance communication between people, physical spaces and digital information. Digitalization is closely linked to human life, people access information and share their lives through the Internet, so the recommendation of not using cell phones in museums a few years ago seems to separate museums from the digitally influenced daily life. Museums are also clearly aware of the impact of digital culture. While museums have been cautious and relatively slow to challenge traditional ways, they are listening to their audiences and rethinking the narrative of presenting cultural heritage in the digital age (Barnes&McPherson, 2019). An increasing number of museums are applying new technologies to keep pace with evolving states of digital being in last decade. Museums are increasingly becoming hybrid-complex and sensory enriched spaces in which virtual (digital) information coexists with physical artifacts (Tzortzi, 2017). Exhibit design and interaction design based on 5G, AR, MR, AI, and other technologies are widely used in museums to enhance the connection between visitors and exhibits, improve visitors' experience in museum, and promote the integration of museum spaces and collections. when curators take advantage of the new means available in exhibition design, which enhance interactivity, convey meaning, and tell stories, they can create exhibitions with greater impact in society (Giannini&Bowen, 2019). So, today's context represents an important research area for the design of interactive experiences supported by digital technologies.

The design practice for museum exhibitions in the digital age has been the application of a wide range of findings from previous museum audience research, collection research and technology research, and has also crossed the boundaries of related research fields, generating new research questions. Some scholars have published reviews of recent applications of specific new technologies (AR, VR, MR) in the field of cultural heritage or museums (Bekele et al., 2018; Challenor, 2019; Qian et al., 2021; Yi&Kim, 2021; Boboc et al., 2022; Chong et al., 2022). Important aspects related to VR/AR/MR technology and the associated technical requirements needed for the development of cultural heritage applications are listed in the study by Bekele et al. (2018). The tracking, display, and interface aspects of AR applications are outlined. In Challenor's review (2019), how AR is used in the field of history education and which AR applications might be acceptable for this field are examined. Research into user experience research, experience design and evaluation methods in the context of technology use has begun to emerge in recent years (Yi&Kim, 2021). These reviews explore the current status and prospects of the application of new technologies in the field of cultural heritage and museums, and all refer to the design of new technologies in their studies. However there are limitations to design considerations based on the application of a single new technology. In many new exhibition projects it can be found that a project will be applied to a composite of multiple technologies, not only the application of a single technology. Because the purpose of exhibition design is to let the visitor have a better viewing experience, this experience itself is a process, in this process there will be a lot of interaction between the visitor and the exhibition, and the feeling of the experience is also affected by many factors. Wang and Xia (2019) focused on human-exhibition interactions and analyzed 1,467 documents using tools with 59 exhibition design factors, 18 audience experience factors, and 14 behavioral data being explored. This study has developed a model that attempts to explain the communicative relationship between exhibitions and humans. Although the model developed by this review is informative but not directly relevant to exhibition design.

This review goes beyond the application of specific technologies to focus on the ways in which design is shaping the museum experience in the digital age. The second section identifies three trends in museum display design in the digital age, all of which have reshaped the relationship between objects and people in museums. The third section summarises a design framework based on recent literature documenting the process of designing museum experiences using new technologies. The research trends reflected in the design framework are discussed in the fourth section.

2 Museum display design trends in the digital age

For designers and museum professionals, the application of new technologies in exhibition design reshapes the relationship between the elements of "people-collection-space", improves the accessibility of collections, and enhances the visitor experience. In recent years, more and more museums and design teams have been exploring the application of new technologies in the field of exhibition design.

2.1 Multisensory interaction in the museum

Most mainstream exhibitions in modern museums still impose 'physical restrictions' on visitors, and although individuals can move freely around the museum, guards, closed cabinets, no-touch signs and camera surveillance all reinforce a top-down orchestration of space. According to Annamma, John and Sherry (2003), viewers can have a multisensory experience by creating an 'virtual body' through visual

experience in the context of specific lighting and display design. However, most still exhibitions focus on visual effects and lack other sensory experiences. Multi-sensory museums, on the other hand, are about understanding art, history and culture by going beyond the limits of vision. They emphasise that the audience can use several senses at the same time, including sight, hearing, touch, smell and taste, to better understand the artefacts, phenomena and cultural knowledge in the museum. The multi-sensory experience is important in shaping and triggering the audience's emotions. so it is becoming a trend for museums to explore enhancing the multisensory experience of visitors in their exhibitions. In the 21st century, technological developments have made it possible for visitors to have a better multisensory experience in museums, responding to the continuous physical sensory needs of visitors.

Visual and auditory integration is the most common of the multisensory integrations implemented in museums. More recently (e.g. Bubaris, 2014; Wiens and de Visscher, 2019), the attention that sound has received in museum practice and scholarship continues unabated. Hutchinson and Eardley (2021) improved sighted viewers' recall of artworks by designing audio-described "guided tours". Marshall et al. (2016) present an interactive piece for an outdoor heritage site, a visitor-perceived personalized multipoint auditory narrative system that automatically plays sounds and stories based on a combination of physical location, visitor proximity, and visitor preferences, which has been tested and found to create evocative experiences for visitors. Everett (2019) summarizes a process-based approach to museum sound design that incorporates sound design principles into the exhibition development process.

Among the implementations of multisensory integration in museums, the integration of touch, together with vision and hearing, are the most frequent senses to be stimulated. Interestingly, according to Constance Classen's study(2007) of early museum visitation records, it is clear that early museum visitors had a richer interaction with the collection: Visitors could touch, play with, and feel the texture or weight of certain exhibits. For reasons of collection conservation and management, most of the exhibits do not provide visitors with the direct multi-sensory experience that they had in earlier viewing experiences. Based on early records, it seems that the physical sensory needs of visitors have remained constant. What has changed is the attitude of museums, which have begun to realise that simply listing and displaying collections does not mobilise the viewer's multi-sensory experience. Museums now seem to be interested in restoring the sense of touch to their exhibitions as a return to the viewer's experience, while retaining the exhibits. In the multi-sensory integration implemented by museums, the integration of the sense of touch with the senses of sight and sound is the most frequently stimulated sense. Previous combinations have included providing visitors with "touch objects" to experience the displayed artifacts. Such as the Victoria and Albert Museum in London (VAM, 2017) using a wise owl supervising the Sculpture Galleries and carved examples of different woods types. Visitors can also press a button next to the object to hear an associated audio description. Despite the simplicity of the exhibition design, it effectively mobilises the multi-sensory experience of the audience. In addition to the use of 'touch objects' to enhance visitors' understanding of the texture of the exhibits themselves, Tate Britain has also explored the use of haptic technology to enhance visitors' experience of visual art. All the senses (sight, sound, touch, smell and taste) are considered in Tate Sensorium (2017), a six-week multisensory display at Tate Britain, London, UK, with a special focus on the sense of touch. A new tactile technique, mid-air haptic technology, is used in the exhibition and combined with sound to enhance the experience of visual art.

Although through taste and smell, external elements are imbibed and ingested into the body, they can dramatically affect bodily moods and responses. However, the use of taste and smell stimuli in exhibitions is more restrictive and can only be used effectively in specific exhibitions. A multi-sensory museum experience that applies the senses of smell and taste is the York Viking Centre (Jorvik, 2017), where multisensory stimuli were used to enrich the experience of a tour concerning the Viking past of the city of York. This experience allowed visitors to touch historical objects (Viking Age artefacts), taste the unsalted, dried cod of the Viking diet, smell the aroma of the corresponding displayed objects, see the animals and inhabitants of the Viking city, and listen to the Viking sagas.

2.2 Immersive experience in the museum

Scholars in the humanities and arts often base their understanding of immersive experiences on the "flow" theory in the field of psychology. This sensation is beyond the level of human experience in daily life, which in turn causes people to yearn and be fascinated by it (Hua J and Chen QH, 2019). Museums are searching for creative ways to use augmented reality (AR) and virtual reality (VR) technology to go beyond the exhibits of the past (American Alliance of Museums 2016). AR, VR, and MR technology have been widely used in museum exhibitions in recent years to bring immersive experiences to visitors. For example, the Xi'an Qinling Bronze Chariot and Horse Museum, which opens in 2021, enhances the cultural experience of visitors through mixed reality technology, augmented reality, holograms and 3D animation to show the topography of monuments and the shape of relics. And immersion can be a powerful and useful property of a tool to enhance presence (Cummings & Bailenson, 2016; Kidd, 2018; Perry, 2019; Sterling 2020), which can be intentionally exploited for powerful communication and influence (He et al. 2018).

Similarly, there are several studies that confirm that immersion experiences in museums increase the learning effectiveness of visitors. The Carnegie Museum of Natural History has developed an application called AR Perpetual Garden using data visualization and bioacoustics. Users can explore the exhibition environment using their cell phones or tablets, creating context-sensitivity experiences for users inside the gallery and outside in the gardens, helping them with their informal learning at the museum (Harrington et al, 2019). Virtual reality technology is used in an exhibition at the Museum of the Han Dynasty Marquisate of the Sea in Nanchang. The explanation of Haihunhou's tomb structure was described through the use of 3D animation, and the transparent screen and display cabinet features increased the sensory experience of the user, in the meantime, viewers could gain a greater knowledge of the exhibition hall's content and cultural heritage (Han and Cui, 2021). An exhibition open since April 19, 2022 at the Leonardiano Museum in Castello dei Conti Guidi, Vinci, allows visitors to interactively understand the process of creation of artworks through an interactive display of digital replicas of the works. The evaluation showed that the digital interactive experience was appreciated by the users and succeeded in transforming content of high scientific value into more attractive and accessible elements (Spadoni et al., 2022). Shen, Min and Aynur (2022) examine the user experience, learning effectiveness, learning behaviors, and learning motivation of 54 young adults in pairs using an immersive virtual reality environment and a multi-touch tabletop to gain a cultural-historical understanding of the traditional Chinese paintings, Spring Morning in the Han Palace and The Night Revels of Han Xizai respectively. The results reveal the immersive virtual reality environment significantly increased the learning effectiveness and motivation compared to the multi-touch tabletop system, particularly in tasks related to recall of details or spatiality.

Immersive exhibitions can present visitors with distant worlds, ancient places or rare and immovable exhibits, giving them a novel experience. In the newly opened Hubei Provincial Museum (2022) hall experience area, set up a holographic projection of the Zenghouyi chimes can be interactive with the visitors, the visitors can use their hands to "ring" the ancient instrument. Visitors can also play the chimes by wearing VR glasses and using the VR handle, prompted by the system. This combination of physical and acoustic experience allows visitors to gain a more comprehensive understanding of the timbre of the ancient instrument, the scenes of their use, and other information that cannot be displayed in traditional exhibits. Similarly, immersive exhibitions can be used to showcase sites and artefacts that are inappropriate to visit. "Rome Reborn"(2022) is an international initiative launched in the mid-1990s by the UCLA Cultural Virtual Reality Laboratory to develop 3D digital models illustrating the urban development of ancient Rome from its foundation to the depopulation of the city in the early Middle Ages. Rome Reborn presented a series of products for personal computers and VR headsets aimed at guiding students and the public in virtual tours of the now-vanished ancient city. Again, Malliri and Siountri (2019) proposed an augmented reality application that utilises 5G and cloud computing technologies aimed at presenting underwater archaeological sites, submerged settlements and shipwrecks to the public in a form of virtual content.

2.3 Non-linear narrative in the museum

The immersive medium, enabled by interactive technologies such as virtual reality and augmented reality, allows the narrative structure of the exhibition's stories to change, transforming the storytelling from a classic linear structure to a more complex non-linear structure. The museum in the digital age is not only acting as a storyteller telling a fixed story presented to visitors through curatorial design, but as a story co-maker in collaboration with visitors' experience in the space (Liu&Lan, 2021).The immersive medium breaks through the dichotomous paradigm of narratology, allowing the listener to intervene in the story at any time throughout its creation, development, and completion, and to have a direct impact on the events or storyline of the story. The immersive narrative must be an experiential exploration, not a discursive relay (Xu&Tu, 2023). New technologies make it possible to present exhibits without a prescribed path, and the narrative that museums tell visitors about the knowledge of cultural objects can break down physical boundaries, allowing visitors to explore the knowledge that interests them according to their own interests.

The recent literature confirms that new technologies have changed the type of experience for visitors. The visit ceases to be passive and becomes engaging and interactive because it is based not only on observation of the finds or exhibited works, but on the opportunity to choose which content to experience, to experiment with their knowledge. Nikolakopoulou et al. (2022) describe an interactive storytelling and projection mapping installation designed for the Mastic Museum on Chios island in Greece. The installation uses interactive projection mapping methods combined with 3D printed models to give visitors tangible interaction to activate video projections presented in a storytelling format. Through new technologies, the non-linear narrative of the museum is not only embodied in specific exhibitions, but is thus extended to a larger spatial and temporal context that should encompass the full range of experiences that the museum offers to its users. Hauser et al. (2022) present a multimodal narrative approach to the presentation of silk heritage in museums, describing how they convey knowledge of digitised silk heritage to visitors through different narratives. Examples include: virtual guides introducing hotspots, socio-historical background information on museums

through interactive timelines, gifts with AR-identifiable information, virtual museum websites with audio-visual information and interaction, video games to explain the pattern design of jacquard looms.

The narrative nature of the immersive medium not only allows for the direct intervention of discourse in the story, but also completes the transfer of power from the narrator to the listener (Tu, 2022). This transfer of narrative power is even more evident in the online platform of the virtual display created by the museum. Google Arts & Culture has an 'Experiments' section that offers unique ways for the public to interact with the collection, such as the t-SNE Map experiment, which uses machine learning to identify visual similarities in the collection and presents thousands of artworks as an interactive 3D view (Figure 3). Through a partnership with MIT and Microsoft, the Metropolitan Museum of Art has developed Gen Studio, an artificial intelligence technology that enables creative visual browsing of the art collection, and Art Explorer, a visual recognition-based tool that uses Microsoft Azure's cognitive search capabilities. ". Through these online platforms, museum visitors become engaged explorers in the narrative, rather than mere listeners to museum professionals.

3 Exhibition design research in digital era

The development of hybrid installations for museums is a new territory for designers and cultural heritage professionals, although many museums have experimented, and these attempts have been made with only a few guidelines and recommendations available. In the context of digital transformation, the rethinking of the use of new technologies and design approaches certainly offers new opportunities for exhibition researchers.

The researcher attempts to suggest factors that need to be considered when using new technologies for display design in museum contexts. Ibrahim and Ali (2018) named some factors important to consider when designing virtual environments for cultural heritage: information design, information presentation, navigation mechanism and environment settings. Pietroni (2019) stressed out the need for better integration between real and virtual concepts and for combining different interaction paradigms, such as tangible interfaces and virtual reality.

There is a relatively well-established body of research on the design and application of specific technologies in the museum. For example, the museum has used mixed reality (MR) technology in a variety of contexts to immerse audiences in a combination of real and digital heritage content, providing users with numerous hybrid ways to interact, typically using six types of interaction: tangible, collaborative, device-based, sensor-based, hybrid and multimodal interfaces (Bekele & Champion, 2019). However, museum experience design often involves the application and design of a variety of techniques depending on the specific project, and several studies in recent years have focused on documenting the design process during project implementation and summarising the design approach.

Museum professionals and designers have also identified some design principles and methods in their concrete project practice. In order to examine the design and production process of exhibitions that have used new digital technologies, it was important to gather descriptive information first, and build toward more general patterns afterwards (Patton 2014).

Using semi-structured expert interviews, Popoli and Derda's (2021) analysis of data following interviews with 14 experts suggests that there are five overarching stages in the twenty-five total steps that constitute the process of designing and producing an immersive exhibition. The five phases: (1)

initial, (2) conceptual, (3) design, (4) production and (5) opening, provide a sequence of steps that clarify the activities of the creative process (Fig.1).

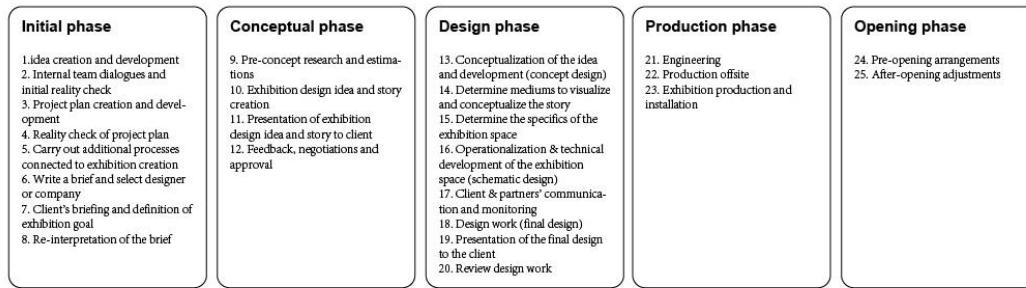


Figure 1. the process of designing and producing an immersive exhibition

It is worth noting that the exhibition design process derived in this study is more similar to the framework of the exhibition workflow. It is clear from this process that museums are placing new demands on experience design and are beginning to seek more external collaboration, reflecting the changes in the way museums operate in the current digital context. In the museum sector, designers and design institutions are beginning to have a greater voice.

To arrive at a framework that more closely resembles the design process, by combining Figure 1 with several other case studies documenting the use of new technologies in exhibition design, a design iteration process can be derived that consists of four main stages: research, design, development and testing. In this iterative process, two further framework structures can be found: the Exploratory Framework and the Application Framework, depending on the purpose of the specific project.

3.1 The Exploratory Framework (适当扩写联合制作过程)

Exhibition projects using the exploratory design framework (Figure 2) are related to technical experimentation or focused experience building, often with a clear goal of a problem to be solved. This goal or problem is presented by the museum, materialised by the tech provider and the designer, and tested by the museum and the audience (mainly the audience). This process results in an assessment of the design experience or other aspects of the usability of a technology application.

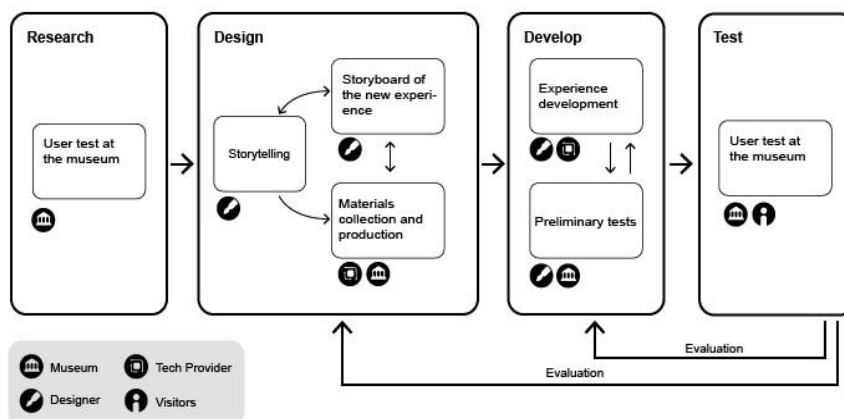


Figure 2. The exploratory framework

A typical project is the Tate Sensorium (Vi et al., 2017). During the research phase of this project, the Tate UK team advised on the selection of artworks based on their availability and suitability (in terms of conservation, safety and other artistic considerations). The research phase involved multiple experts, gallery professionals and external experts in different fields (at Flying Object, Sussex University and other independent sensory experts). Tate developed the content for the exhibition (selection of appropriate interpretive/contextual information relevant to each work), which was ultimately translated into 'sensory form' (e.g. audio material). During the design and development phase, the suitability of the sensory stimuli was then determined through consideration of literature on multi-sensory perception and experience (by a university research team), advice from sensory experts, and an iterative creative process (involving experimentation with different senses). During the testing phase, the project captured the experiences of 2,500 visitors through a questionnaire during the exhibition, which was analysed to quantify the added value of the designed sensory enhancements to the painting experience. From these, 50 visitors were selected for interviews to obtain qualitative data. This data was used to provide an evaluation and recommendations for the design of the multi-sensory installation. Other display projects using a similar design framework include the FabricVR project (Arayaphan et al., 2022), the Interactive Crane (Vosinakis et al., 2020), the "Mouseion Topos" project (Chatzigrigoriou et al., 2021), The MARSS project (Spadoni et al., 2022) and so on.

3.2 The Application Framework

For broad objectives such as enhancing the visitor experience, making exhibition information more accessible, or focusing on specific groups (e.g. children), museums use the application design framework (Figure 3). In this case, both museums and designers need to make a greater effort to identify user needs, and the audience needs to be involved earlier in the design process. The development phase also requires more validation and modification of the design in conjunction with the audience.

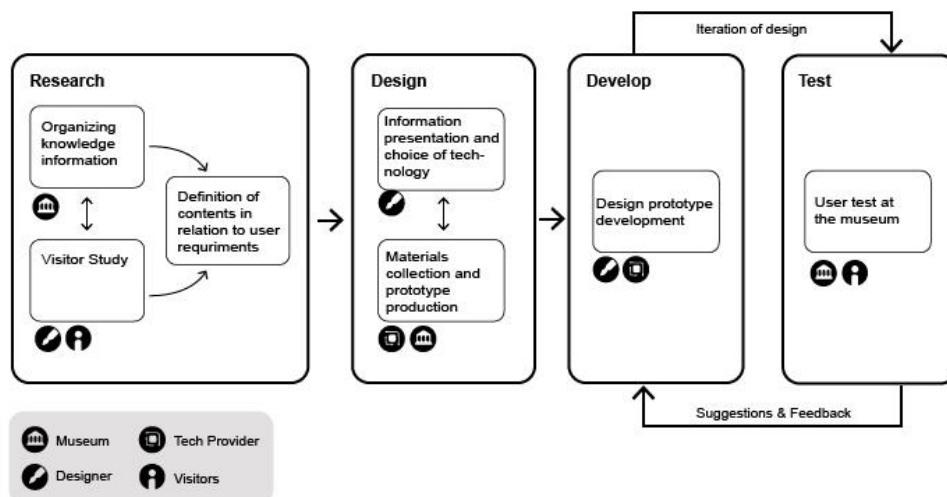


Figure 3. The application framework

A typical project is the Refugi 307 (Schaper et al., 2018). During the research phase, the researcher conducted semi-structured interviews with four teachers and three tour guides, and held three project meetings at the museum, where the design team and the museum professionals worked out a

proposal for the user research. This design phase involved forty children from two school classes. The researchers observed and recorded users during their visit: students' interactions within the space (movements, gestures, postures); facial and verbal expressions; social interactions with each other, teachers and guides in different parts of the shelter. Interviews with these audiences were then conducted in small groups to generate design needs. Based on the results of the research phase described above, during the design phase the project team defined seven activities based on the use of two Philips PicoPix PPX3414 pico projectors. Guides and 20 students were invited to participate in the development and testing phase to test the prototypes. Activities were developed for the site to support digital enhancements involving physical space. Other display projects using a similar design framework include "Svevo" (Fenu& Pittarello, 2018), the Old City, Zuoying (Liu&Lin, 2021), The Mastic Museum Design Project (Nikolakopoulou, et al., 2022) and so on.

4 Research trends in display design methods

The above studies show that at different stages of the creative process the museum team includes experts, designers and visitors from different disciplines. Most researchers emphasise the need for close collaboration between different disciplines when designing and developing new technological displays.

4.1 Seeking methods and tool development for closer co-design

The complexity of collaboration in the museum context has long been highlighted by studies that point to the challenges of collaborating internally across different museum staff groups or communities of practice, and externally with designers and users. (Davies 2010; Knudsen&Olesen 2019; Lee 2007; Macdonald 2002).

A layer of complexity has been added by recent technological developments. Most researchers of the field highlight the need for closer collaboration between multiple disciplines throughout the design and development of display installations involving new technologies. This has also led to calls for new ways of working in museums. As a result, co-design methods have gained acceptance in museums when developing digitally-enhanced museum experiences (Avram, Cioffi, and Maye 2019; Stuedahl 2019). In the existing research from both the museological and design communities around digitally-focused collaboration, there are two research paths, one driven by pre-determined research questions or requirements. This approach is suitable for known problems to which participants have clearly defined relationships. The second approach aims at new and innovative ideas that are expected to be generated outside of a specific discipline; this tendency emphasises an experimentation and engagement with audiences, which takes precedence over particular outcomes (Arrigoni, Schofield and Pisanty, 2020). Pietroni(2019) described a collaborative design process consisting of: (a) an initial phase of discovery, where the design team understands the needs and constraints, (b) a creative phase where key ideas are implemented and tested and in some cases prototypes are evaluated in situ, and (c) the development phase that leads to the final installation for public use. In another study, Cesario et al. (2018) prepared and studied a co-design activity that was more participatory and was mostly led by end-users. A group of teenagers together with the researcher jointly designed, created and evaluated medium-fidelity prototype games for a museum using augmented reality technology. The collaborative design of the Pietroni study is closer to the former, while the study by Cesario et al. is closer to the latter.

Although the importance of collaborative design in museums has been highlighted, there are few collaborative design tools/platforms in the museum context. Olesen, Holdgaard and Sundnes (2020) have developed a paper-based co-design tool, called The ASAP map, which helps people working across departments in museums to raise their awareness of the level of knowledge sharing and helps to identify and open up discussions on conflicting issues. The map was seen as a way to professionalise digital experience design processes in museum practice and to work more systematically with the selected concepts, resulting in better solutions for audiences. However, the co-design tools mentioned in this study were developed for interdepartmental museum collaboration. The tools and methods of collaboration between museum professionals, designers, digital technicians and audiences need to be further explored by scholars.

4.2 Research and methods to uncover audience needs

Visitors are playing an increasingly important role in the exhibition design process. Inviting them to participate in new or redesigned museum exhibitions is often at the heart of museums embarking on a co-design journey. Better understanding the needs of audiences is the essence of audience participation in museum co-design.

In fact, audience research has been an important part of museum research since the early 20th century. The Committee on Audience Research and Evaluation (CARE) refers to the museum research process of systematically gathering knowledge about actual and potential audiences and using it to plan and implement activities as audience research. In the mid to late 20th century, audience research became visible in scholarship. John H. Falk, Marilyn Hood, McQuail, Moussouri, etc. focus mainly on "audience perception" and "emotion generation". The focus has shifted to the human heart and its experience from the original focus on human behaviour. Bitgood, Bechtel, Loomis, Moscardo and others focus on audience research, the importance of environmental psychology to the building of other disciplines, and the influence of the environment on the role of cognitive behaviour. Ames, M.M., Penney, D.W.M. have carried out research on different groups, particularly minority or disadvantaged groups. The audience research model developed by Loomis shows that audience research consists of three elements: audience engagement, visit process and visit outcomes. As a result, the outcomes of audience research can also be classified as behavioural research during participation, post-participation effects research, pre-participation motivation and socio-cultural context research. These findings are obviously needed in the exhibition design process, but their research findings are not well translated into design. Current audience research is rarely carried out for the purpose of improving specific exhibition design, so it is worth considering how existing audience research could be used to identify design problems, compared to user research carried out in the design process.

At the same time, digital technologies are opening up new possibilities for the design of museum displays. They are also creating new expectations of how visitors/users should engage with museums. Digital states of being and identity are changing visitor behaviour, reshaping the identity of the museum and helping visitors think about the world and their evolving social and cultural consciousness in new ways. These changes also have profound implications for museum audience research: the target audience is shifting from real audiences to a combination of real and virtual audiences; the factors of impact assessment are becoming more diverse; and data collection is moving from manual to device. The new context of change also requires a new approach to understanding user needs.

5 Conclusion

Display design trends in the digital age are reviewed in this article. As technology has evolved, so have museums' display designs. Three design trends can be identified in exhibitions: multi-sensory, immersive and non-linear narrative. Multi-sensory design can transcend the physical attributes of the collection itself, stimulating the audience's multi-sensory experience through multiple media. Through the design of immersive displays, it is possible to extend the visual information of the collection itself and to improve the accessibility of the knowledge and the experience of the viewer by visualising the hidden information of the collection. By designing non-linear narrative, the narrative structure of the museum exhibition can be diversified, so that the audience's experience in the museum can be changed from knowledge transcription to exploration.

Researchers' attention has shifted from technical feasibility to thinking about the design process and generating design methodologies as museums continue to explore new display designs. Two design frameworks, the exploratory design framework and the applied design framework, have been summarised from case studies of museum displays that document design processes and design methods. Within these two design frameworks it is easy to identify two trends in display design research influenced by digital technology: closer collaborative design research and research to identify audience needs. There is currently a limited amount of research on the transformation of collaborative design research and user research in the field of museum display design, and these two trends are areas of research that the field of museum display design could focus on in the future.

There are also shortcomings in this study, which will be addressed by future research. The design framework in the study is based on a compilation of museum display case studies from recent years, which has certain limitations. The reason is that the number of museum showcases far exceeds the number of studies. In further work, the design framework that has been summarised so far will be adapted and refined through field research in museum exhibitions and through semi-structured interviews with designers of display cases.

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