PhD Research :

VIRTUAL EXPERIENCE IN AUGMENTED EXHIBITION

Virtual technology application in real museums and its impact on exhibition spaces

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Virtual technology application in real museums and its impact on exhibition spaces

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ABSTRACT

The museum, undertaking to demonstrate the starting point of a particular country and regional civilization, is a country or a region's "cultural genes" that integrate functions of collection, education, academic research, international exchanges and cooperation, tourism, and others one place. Therefore, the museum's design is crucial to embody the museum's level and plays an essential role in the museum undertaking. The museum, as a social public service agency, is an essential part of social culture. Its preservation and study of the antiques aim to contribute to society's harmonious development and serve the social public. Exhibitions are the most effective spiritual and cultural products provided to society by the museum. It is an important means of social service, particularly the application of the novel exhibition methods in modern museum brought by the influence of the new technological revolution. Museums have always played a crucial role in narrating identities, and have been involved in their production and construction. The accelerated planetary circulation of people(s), objects, ideas and information, and the increasing encounter and hybridization of cultures, languages and histories are consistently challenging the traditional understandings of memory, cultural belonging and identity as they have usually been proposed until recently in European museums. In this framework, the politics and practices of museum representation are being questioned in their ability to depict and convey the complexities of present political, social and cultural scenarios and efficiently address diversified and multicultural audiences.

The development of technology is changing even more rapidly in recent years, which brings more challenges and opportunities to re-consider about the future

display space. To accommodate this change, the museum and exhibition space needs to be adjusted accordingly. Furthermore, digital exhibits, or virtual exhibits, have become commonplace in museums, and this intangible information is augmented to the exhibition space. These virtual elements, together with the original exhibition space, constitute a new space, so-called augmented space. In this new space provided by technical support, users in the museum will have incredible chemical reactions with exhibits, spaces and even other visitors. Under the premise of technological development, the diversity of virtual exhibits and augmented spaces has changed the spatial form of museums and users' interaction patterns.

This research, will try to explain the new vision technology, mainly referring to one kind of virtual vision technology, augmented reality (AR), and virtual reality (VR) for the museum. VR can be considered an extreme form of AR. It can be said that AR is an application form of VR essence of A/VR to construct virtual exhibits digitally and display them to visitors through different devices. Simultaneously, it makes a more in-depth discussion of how the scientific and technological revolution changes the way museum exhibitions, spatial composition and interaction paradigm. Then proposes a design approach driven by user experience based on applications in the digital age and museum space experience. Redefines the relationship among visitors, exhibits, museum spaces, and curators. On this basis, try to estimate the technological development in the future, while discussing the new forms and reshaping museums and their spaces in the near future under the influence of virtual technology.

CONTENTS

CHAPTER 0

Introduction

0.1 Augmented Exhibition

Augmented exhibition in this research is one kind of exhibition using an image, video, or interactive 3D model constructed using digital means inside a real space. In recent years, especially after the widespread adoption of smartphones, more and more exhibitions have offered this new way of exhibiting a seemingly empty showcase or place used as a smart device to simulate a digital object or space.

Unlike traditional digital media such as led screens, projection displays, the augmented exhibition has the following properties: combines real and virtual objects in real space or environment; runs interactively, and renders in realtime, then aligns real and virtual objects with each other. As a visually-oriented public space, exhibition space is most suitable for augmented reality which is also a visually-oriented new technology.

The augmented exhibition can be seen as a new form of space recreated by digital technology in the original exhibition space. The augmented exhibition is not only the digital reproduction of physical exhibits, but also a new type of re-created exhibits. It can either give additional information to the physical exhibits, or it can be a virtual element that is completely equivalent to the physical exhibits. In the augmented exhibition, virtual information, media platform and interactions work together to rebuild relationships among exhibits, space and users.

0.2 Virtual Experience

Virtual Experience refers to the behaviour and feedback made by the user after the reality of the virtual object replaces the real space. The augmented experience can be easily understood as a tool of virtual "layers overlaying" where the extra layering information is applied over the real physical space. *"Augmented space research gives us new terms with which to think about previous spatial practices. Before we would think of an architect, a fresco painter, or a display designer working to combine architecture and images, or architecture and text, or to incorporate different symbolic systems in one spatial construction, we can now say that all of them were working on the problem of augmented space. The problem, that is, of how to overlay physical space with layers of data. Therefore, to imagine what can be done culturally with augmented spaces, we may begin by combing cultural history for useful precedents"* (Manovich 2005, p.13)[1]. From the user's point of view, the augmented experience is a comprehensive experience based on digital technology and virtual reality. The result of this experience is both close to reality and provides virtual

1. Manovich, Lev. "The poetics of augmented space: Learning from Prada." Accessed online 31.3 (2002): 13.

construction that cannot be brought from the real world. The virtual experience redefines the connection and interaction between users and exhibits. At the same time, it also changes the original spatial cognition through augmented reality technology. Finally, users, exhibits and space are intertwined to a new experience form.

0.3 Real, Virtual and Augmented

The terms AR and VR have appeared frequently in people's lives in recent years. More than just graphics and technology, these new words are increasingly appearing in the daily lives of ordinary people. Especially after the smartphone has a certain penetration rate, this technology has gradually shifted from the experimental stage to the marketization stage.

Apple CEO Tim Cook[1] has a fairly positive attitude towards the development of AR. *"I see AR as being profound,"* Cook said on the company's first-quarter earnings call on Thursday. *"AR has the ability to amplify human performance instead of isolating humans. So I am a huge, huge believer in AR. We put a lot of energy on AR. We're moving very fast. "*

1. Timothy Donald Cook (born November 1, 1960)is an American business executive and industrial engineer. Cook is the chief executive officer of Apple Inc., and previously served as the company's chief operating officer under its cofounder Steve Jobs.

However, the difference between AR, VR and traditional digital technology is still very confusing to many people. For this, this paper will discuss these concepts at the beginning and try to identify related concepts and further propose augmented exhibitions for the next phase research.

Broadly speaking, any non-real virtual element produced by digital simulation can be called an extension or enhancement of reality. For example, the music heard through the headphones, and the various images displayed on the electronic screen are all enhancement of reality. However, augmented reality or augmented exhibition is not only this basic level of enhancement. More than "enhancements", they are "additions" to reality, while AR could be seen as an effective "extension" of reality.

The most significant difference between the augmented reality (AR technology) referred to in this paper, and the traditional electronic screen is the immersion it brings. The so-called "immersion" is a perception of being physically present in a non-physical world. The perception is created by surrounding the user of the virtual vision system in images, sound or other stimuli that provide an engrossing total environment. In order to achieve this state, unreal objects generated by virtual technology need to interact with the real world and keep the perspective the same as the real environment which users can see. At the same time, when the user's observation position, behavior, etc. change, the virtual object will make real-time changes to this change. This change is often based on fast rendering technology to ensure that this immersion will not be broken.

Although according to the current technology, the isolation caused by the device (mobile phone, tablet or glasses) cannot be wholly eliminated, its basic operation mode, feedback mechanism and the effect finally presented can basically achieve the immersion needed for augmented reality.
In order to better explain these things, I have made the following analysis diagrams. Through this set of diagrams, we can more clearly understand the difference between augmented reality and traditional electronic display. The following figure lists three

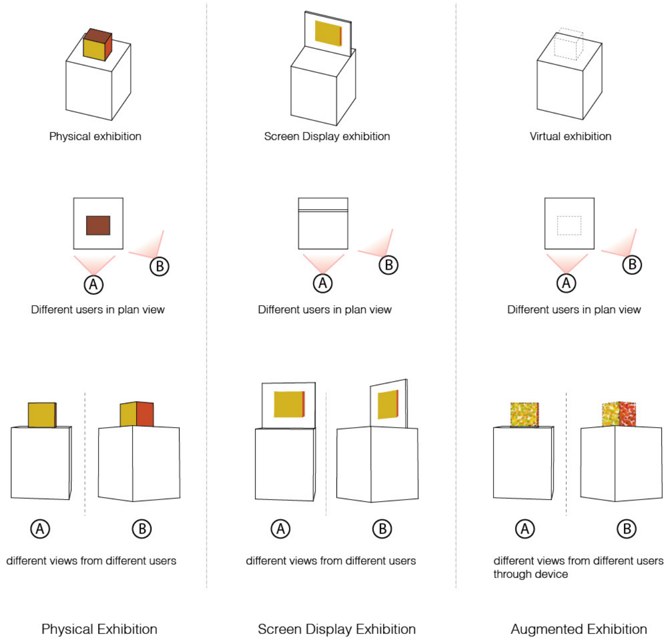

Fig.0.1. Diagram of real, virtual and augmented
Source: Made by author

exhibition methods, physical exhibition, electronic screen display, and virtual augmented display.

From the figure, we can clearly understand the relationship between users and exhibits under different exhibition modes. The 3D model in the traditional method is presented to the user on the screen (as shown in the middle column). When the user is in different positions, he cannot see different parts of the exhibit. The real experience is that the user perceives different dimensions of the exhibit through the movement of the line of sight (as shown in the left column). Augmented reality is a useful link between the virtual exhibits and the real experience. With the help of technology, AR can analyze the existing space and finally communicate the virtual objects to the user with the correct interaction logic (as shown in the right

column).
Virtual Reality (VR) could be a slightly different situation. VR refers to wear a head-mounted device to put users into an immersive digital world through an entirely virtual form. This kind of virtual reality can be regarded as an extreme form of AR; that is, all objects seen by users are created using AR technology. All these virtual objects together constitute virtual reality which is not related to a specific physical space.

0.4 Research Objective

The research discusses around the questions:

What is augmented exhibition and virtual experience?
In which way can it make sense in relation to architecture and art?
How is the application status of virtual vision technology in museums?
What are the advantages and disadvantages of AR and VR technology in the museum experience?
How can the AR impact museum space and design?
Why go to the museum to experience the virtual space which can be simulated anywhere?
How to improve the immersive experience in museums through virtual vision technologies?
What are the expected and recommendable limits for its applications in the museums?

To address these questions, the main objective of the research is: building a new approach for enhancing the experience through AR and VR in museums. And the specific objectives are:

Analyzing the AR in the area of museum design and their experience.

- Designing a experience-based conceptual model for the use of immersive experience design through AR and VR
- Defining the emerging AR and VR in the field of museum design
- Defining the key parameters in augmented exhibition
- Discussing the value and trends of physical museums under the influence of virtual experiences
- Defining the reshaping level based on the type of virtual element and its proportion in the real space.
- Discussing the meaning, appropriateness, and limits in relation to architecture and art.

As a result, this research will discuss the combination of virtual space and real space, especially in the museum space, studying how digital technology and virtual exhibits interact and influence each other. Finally, through research, through virtual exhibit, augmented exhibition and environment, enhance the experience of visiting a museum in a practical way.

0.5 Research Methodology

The research methodology is structured in three phases:

1. Collective and Exploratory Phase

    1.1 Literature Research
    - Contextual Review: New technologies used in museums, the impact of technology on space.
    - Augmented Exhibition: Virtual vision technologies, working principle and historical development.

- Virtual Experience: New space created by virtual digital technology and the experience it brings to the user.

1.2 Basic Survey
- Based on the current status of VR and AR applications in museums, a universal survey was conducted to gain users' understanding and acceptance of this new technology, in order to get first-hand data that have value for our research.

1.3 Interviews
- Software Developer: The development of AR and VR in design field
- Architects: Architect's attitude towards AR and VR
- Museum Director: The current status of using AR and VR in museums

1.4 Theoretical exploration
- The theoretical research is mainly on three aspects, including the theory of museology, digital product design(user experience) and architectural space. Through the comprehensive comparison and research of the theory, the theoretical basis of this research is determined.

1.5 Case Study
- Classify by museum type: science and technology museum, art museum, site museum.
- Classify by distinguishing criterion: inspiration, space, technology and user experience.
- Cases Study will include seven detialed cases and sixteen simplified cases.

All the research stages will be guitically discussed and addressed from the poin tview of architecture. As the first part of the thesis research, literature research is essential. Through this phase of research, I will collect some basic research on museums and interior design. In this part of the study, the subjects will be divided into two parts, one is from a spatial perspective, to explore the changes brought by new technologies in the shape of museum space, experience design, and the interactive relationship between visitors and exhibits. The other part is from different scientific and technological means (AR and VR), as a non-human object to explore the possibility of various scientific and technical pieces of equipment to create immersive spaces.

Technology plays an essential role in the study of immersion and experience. Through studying the history, development, advantages and disadvantages of technologies, discover the revolution which it can bring in the exhibition space, and based on this, imagine how the near future technological updates will bring about impact and change on museum space design. Since a large part of the project's research involves technological devices and user experience, people will also be visited as the focus of the entire study. During the pre-collection and collation process, I will conduct targeted general interviews with three groups, asking professionals (interior designers and related project researchers), non-professionals (visitors) and technology developers, for their opinions and views on immersive spaces.

Having mastered the preliminary literature on immersive spaces and reports from interviews with relevant people, I will begin focusing on a case study of immersive spaces, selecting the most representative museums and exhibition spaces according to the different categories and doing a fundamental analysis of the immersive spaces created using high-tech tools.

2. Investigation

2.1 Example Analysis

- Data Analysis: From the data point of view, analyze the application of VR and AR in museums, such as time of use, display area, proportion of exhibition content, etc.
- Environment Analysis: From the environmental point of view, analyze the influence of VR and AR on museum space, the combination and comparison of virtual space and real space.
- Behavior Analysis: From the behavior point of view, analyze the specific behavior of the user in the use of AR and VR, the way of use and the understanding and interaction inside the virtual space in museums.

2.2 Experience-based conceptual model

- Investigate an experience-based conceptual model in museum interior design and virtual space design.
- Comparing the similarities and differences between spatial design and digital product design in the user experience level parameters.
- Create a technology-driven innovation strategy in museum space design(at real and virtual level).

2.3 Ethnography

- Taking observation and participation observation as the main research method, the visitors are using the behavior and interaction methods in virtual vision technology, and studying its influence on the museum space.

As mentioned above, this research is not only about immersive space and interior design, but also about user experience and virtual space construction, so the ethnographic research method is more suitable for the methodology in the investigation stage. Ethnography understands people as dynamic subjects and has developed a series of methods to explore how people perceive and communicate with each other and with their surrounding environment. The core of classical ethnography is in-depth interviews and participatory observation in qualitative research, in which researchers pay close attention to the daily lives and behaviors of people living in the space understudy for a long period of time. Because of the different social attributes of visitors in different museums, classical field research may face some adjustments. Firstly, museum visitors are not generally regarded as homogenous social groups with different purposes and spatial experiences. Secondly, when we focus on the museum experience space, there will be a large number of visitors just passing through space and did not participate in certain exhibits and activities, especially older people need longer time to learn and adapt to new technologies. Thirdly, traditional field research requires significant human and material resources, as well as more detailed information and survey data from the internal institutions of the museums.

Therefore, we need to conduct simplified field investigations that can still give us an effective ethnographic approach to the experience of different groups of people in the museum's air and the perception of visitors in the virtual or augmented space mode. In this research, I will use the observation methods most commonly used in the ethnographic methodology. As John D. Brewer[1] mentioned in his book *"Ethnography"*: *data collection methods are meant to capture the "social meanings and ordinary activities "of people*

1. John David Brewer HDSSc, MRIA, FRSE, FAcSS, FRSA is an Irish-British sociologist, former President of the British Sociological Association (2009–12), and Professor of Post Conflict Studies in the Senator George J Mitchell Institute for Global Peace, Security and Justice at Queen's University Belfast (2013-), and Honorary Professor Extraordinary, Stellenbosch University (2017-).

(informants) in "naturally occurring settings." that are commonly referred to as "the field." The goal is to collect data in such a way that the researcher imposes a minimal amount of personal bias in the data. Multiple methods of data collection may be employed to facilitate a relationship that allows for a more personal and in-depth portrait of the informants and their community. These can include participant observation, field notes, interviews, and surveys.[1] The main purpose is to observe and record the behavior of visitors of different user attributes regarding the use of immersive spaces in museums, the use of time (study time, adaptation time, experience time), etc.

1. Brewer, John. 2000. *Ethnography.* Philadelphia: Open University Press.

The investigation focused on the use and experience of immersive spaces in museums: why they are here, how they differ from static exhibition spaces, their acceptance of virtual or semi-virtual immersive spaces created by high technology, what they like, what they dislike, and whether they interact with other users. When these first-hand data and reports are collected, they will be of great help to me in the design of immersive spaces and the involvement of scientific and technological means. Although the current phase of the survey is only at the beginning, the results of the field survey will play a crucial role in subsequent research and design as time progresses, and the number of samples expands.

Digital ethnography is also an important method in this research. In view of a large amount of content in this research involving high-tech applications, these applications and their user feedback are often based on online research. The main user group of the virtual exhibition has a high degree of overlap with the main user group of the Internet community. Through digital ethnographic research, we can provide more favourable help for the application of virtual technology in museums. Digital ethnography can be seen as virtual ethnography. *Digital ethnography allows for a lot more opportunities to look at different cultures and societies. Traditional ethnography may use videos or images, but digital ethnography goes more in-depth. (Wikipedia, 2020).* For example, digital ethnographers would collect the data and comments from social media and museum official website or application so that people's interactions, behaviors and appraisal can be studied. Especially at an uncertain period when the COVID-19[1] epidemic raged, Internet applications carried more social and culture responsibilities. During the epidemic, many museums have launched virtual online exhibitions, or brought artworks into the homes of visitors through AR. These online application of museums also provides another representation method in the quarantine period.

1. Coronavirus disease 2019 (COVID-19) is an infectious disease caused by severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2). In order to combat the epidemic, many countries have adopted measures to restrict residents from going out, quarantine at home, and smartingwork.

3. Experimental

3.1 Pilot Project

- SUSAR2017: Seeds on Mars. Cooperation with Stefano Boeri Architetti
- VR Project: Impossible Space through Virtual Reality: Rebuild Escher's Relativity

3.2 Hypothesis and conjecture

- Based on the forward-looking development of technology, discuss the application of virtual elements in future urban and architectural design. And challenge traditional architecture, especially for architectural design and aesthetic design.

This part of the study should be based on the findings of the above collection and investigation. The analysis of the case data resulted in a series of guidelines and recommendations. Including how to create a better user experience immersive spaces through high technology, trying to sum up the advantages and disadvantages of the immersive space created by the existing scientific and technological equipment, looking for the possibility of possible field projects, that is, the use of new scientific and technological means in a museum to assist in the design and construction of an immersive space.

In the conclusion section, it will provide an overall summary of the research stages and topics under a critical point view; present a hypothesis of future museums and urban spaces based on virtual vision technology and reaffirm the meaning, limits of ICT applications in the "real body" of the museums, as an important cultural institution and a special type of architectural spaces.

0.6 Short List of Bibliography

1. Allen, Jamie, and Eleonora Lupo. *Representing museum technologies.* Politecnico di Milano, 2012.
2. Azuma, Ronald T. "A survey of augmented reality." *Presence: Teleoperators & Virtual Environments* 6.4 (1997): 355-385.
3. Basso Peressut, G. L. and Clelia Pozzi. *Museums in an age of migrations: questions, challenges, perspectives.* EU-Polimi, 2012.
4. Brewer, J. D. *Ethnography*. Philadephia, 2002
5. Latour, Bruno. "The Berlin key or how to do words with things." *Matter, materiality and modern culture* (2000): 10-21.
6. Lucas, Ray. *Research methods for architecture. London: Laurence King Publishing*, 2016.
7. Manovich, Lev. "The poetics of augmented space." *Visual communication* 5.2 (2006): 219-240.
8. Tresch, John. "Technological world-pictures: cosmic things and cosmograms." *Isis* 98.1 (2007): 84-99.
9. Yaneva, Albena. *Made by the Office for Metropolitan Architecture: an ethnography of design.* 010 Publishers, 2009.
10. Wikipedia. "Ethnography". Accessed May 22, 2020. https://en.wikipedia.org/wiki/Ethnography

CHAPTER 1

Museum Space: From Real Experience to Virtual Experience

1.1 Introduction

According to Gianni Ottolini said: *"In today's culture of design some conceptual extremes, all too realistic in a consumer society, believe that the setting is now the only possible form of architecture, wired to the ephemeral trendy languages and buildings made (and unmade) in faster (and approximate) ways, or even to virtual incorporeity, that is the opposite of architectural built. An apparent compromise would leave to architecture stones and mortar (that is construction done in the traditional ways and its conservation), and to industrial design the only assembly and new means of electronic communication, and therefore the most technologically sophisticated construction and almost all current exhibitions."* This rapid consumption pattern coincides with the pace of renewal in the era of great

Fig.1.1: Print from a periodical featuring a view of the Egyptian sculpture gallery with new artificial lighting, entitled "Electric lighting of the British Museum" (1890). 'The Illustrated London News' p. 164. Courtesy of the British Museum.

1. Ambienti/Environments, Curated by Marina Pugliese, Barbara Ferriani and Vicente Todolí / 21 September 2017 - 25, February 2018.

Fig.1.2: Interior of Villa e Collezione Panza - FAI
Source: https://luoghidelcontemporaneo.beniculturali.it/villa-e-collezione-panza---fai

Fig.1.3: "Alexandra Pirici: Co-natural," 2018. Exhibition view: New Museum, New York,
Source: Photograph by Julieta Carvantes, https://www.newmuseum.org/exhibitions/view/alexandra-pirici

technological change in which we live today.

As early as the early 20th century, with the continuous development of the Second Industrial Revolution (represented by the large-scale application of electricity and the invention of electric lights), the quality of human life has been dramatically improved. With the help of the technology of the electricity, the exhibition space has also been completely upgraded, the museum can no longer rely solely on natural lighting, but use electronic lighting, air conditioning and other technologies can make the exhibits more flexible display formats. These new technologies can support the architects and designers express their ideas better (Fig.1.1). Moreover, the use of technology can also be the main construction of an exhibition, such as the exhibition of Lucio Fontana held in Hangar Biccoca[1], and Villa e Collezione Panza (Fig.1.2),

In fact, the development of technology is changing even more rapidly in recent years, which brings more challenges but also opportunities to re-consider about the future exhibition space. For example, visual technology like VR and AR have already changed the experience of the exhibition and the interaction between visitors and exhibits; visual techniques such as holographic projection(Fig.1.3) can provide a more luxurious visual experience, rather than using a two-dimensional screen or curtain to simulate the three-dimensional one. Facing technological progress, the museum and exhibition space needs to be adjusted accordingly. Furthermore, digital exhibits, or virtual exhibits, have become commonplace in museums, and this intangible information is augmented to the exhibition space. These virtual elements, together with the original exhibition space constitute a new space, so-called augmented space. In this new space provided by technical support, visitors in the museum will have incredible reactions and relationship with exhibits, spaces and even other visitors. Under the premise of technological development, the diversity of virtual exhibits and augmented spaces has indeed changed the spatial form of museums and the users' interaction patterns.

1.2 The Changing Trend of Exhibition Spaces

1.2.1 From White Box to Black Box

In 1976, artist Brian O'Doherty[1] published a three-part essay named "Inside the White Cube." In this essay, he said *"The outside world must not come in, so windows are usually sealed off. Walls are painted white. The ceiling becomes the source of light. […] The art is free, as the saying used to go, 'to take on its own life.'"* Today, the history of the white cube and exhibitions are inseparable. There is no doubt that white box can provide a relatively pure and clean user experience. This "white cube" eliminates as much interference as possible between the audience and the exhibits, can even make the audience ignore the existence of space(Fig.1.4).

1. Brian O'Doherty (born May 1928 in Ballaghaderreen, County Roscommon, Ireland) is an Irish art critic, writer, artist, and academic.

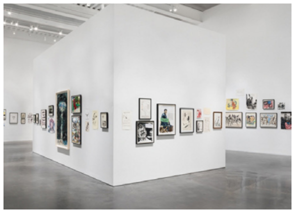

Fig.1.4: Installation view of "Raymond Pettibon: A Pen of All Work,", New Museum, New York, February 8-April 9, 2017.
Source: https://www.galleriesnow.net/shows/raymond-pettibon-a-pen-of-all-work/

However, "Blake Box," the opposite words of "White Cube," became the new exhibition space trend. The "black box," as it is called here, is not made of black material or spray-painted to make it black; more specifically, through the lighting and space to make it into a "dark box." (Fig.1.5) For a familiar example, cinema is a typical black box. If the exhibition space is defined to give the audience a particular set of things, the cinema seems to be understood as an exhibition space. So there are the questions: what is

Fig.1.5: "Sala del Cartone di Raffaello", Veneranda Biblioteca Ambrosiana, Milan, 2019.
Source: https://www.stefanoboeriarchitetti.net/project/sala-del-cartone-di-raffaello/

the difference between this black box and the white box, and why is it that modern technology favours the black box?

Physically, many projection images or displays are best viewed in low lighting conditions, while newer holographic projection and AR technologies, for example, minimize the impact of other light sources. Therefore, the implementation of adjustable lighting systems was the most apparent consideration made by black cube exhibition spaces. However, many installations require space itself to be controlled. The typical black cube would hence have movable walls in its interior. Some artists may even have preferences as to the temperature of the environment. The essential idea behind the black cube museums is that the museum should be malleable to any artwork's needs. The Pompidou Centre is early architectural evidence of this way of thinking. However, in the Pompidou Centre, the museum's hi-tech architecture form influences the way the artwork is viewed. The majority of black cube prefer to develop an environment in which artworks can be viewed objectively, an idea taken from the modernist white cube.

Psychologically, the black box's user experience and the white box are decidedly different, and the purity of the white box will make the exhibits as undisturbed as possible from the rest of the elements. The black box will focus the user's visual centre on the exhibits themselves, in the exact sense of putting the user in the dark and making the user disappear together in the dark, and the so-called immersive experience. Also, people pay more attention to privacy when they interact with the exhibition, and do not want to focus on the rest of the users, especially when the interaction is relatively new (e.g., motion capture). Thus, the black box allows users to pay more attention to the exhibits than to the interactive behaviour of other users.

The technical link requirements have led to changes in the space environment, in order to more prominent immersion, more emphasis on the existence of virtual objects in the real physical space. From the white box to the black box is a new trend in the exhibition space under technological progress.

1.2.2 From Traditional Interaction to Digital Interaction

In recent years, visitors hope to gain greater interactivity in the exhibition space, especially in non-art exhibitions. Both children and adults are attracted to the interactive devices. As a result, the most popular areas of the exhibition are often interactive and highly participatory. It seems that museums also function as a space of leisure and entertainment. *Indeed, museums are one of the central provisions for entertainment which are widely accessible to the general public*[1] (John H. Falk and Lynn D. Dierking, 2000). Thus, more interactive installations in exhibition space is a trend of the future.

1. John H. Falk and Lynn D. Dierking. 2000. *Learning from Museums: Visitor Experiences and the Making of Meaning.* Walnut Creek: Altamira Press

Interactive devices are nothing new. As early as the early 20th century, a variety of interactive devices for visitors to use have been widely used in various science and technology exhibitions (as shown in Fig.1.6). But this interaction pattern is a physical interaction, such as a common mechanical device that changes the asset by touching certain buttons. The experience elevation of this interaction is obvious, which is why we can see that there are even hours of long teams waiting for few minutes of entertainment in many exhibition spaces before they can be played.
It seems that technological advances can slowly solve

Fig.1.6: Children with interactives, Children's Gallery, Science Museum, London, 1951.
Source: (ScM Photo Studio (1951) as cited in SSPL prints. (n.d.))

this problem. Given the popularity of digital devices, visitors can use more ways to participate and interact with exhibits, and multiple interactive modes also increase the richness of the space. AR is one kind of these technologies. The first functional AR systems that provided immersive mixed reality experiences for users were invented in the early 1990s, starting with the Virtual Fixtures system developed at the U.S. Air Force's Armstrong Labs[1] in 1992. Nowadays, with augmented reality, visitors can use a simple smartphone to discover more information about a piece of art interactively. For example, placing a smartphone or tablet over an ancient statue could display missing parts that had broken off – giving the visitor a glimpse of how it would have looked when it was new. Because AR responds to your movement in the environment, the experience is also completely 3D. That means visitors can interact with specific devices on the site, which an interactive device can be paired with multiple visitors to enhance the user experience. At the same time, the sense of unknownness and the desire to explore brought by digital interaction can more attract users to use these devices (as shown in Fig.1.7). Digital interactions have the advantage of being updated with traditional interactions. In the contemporary era of rapid development, museums and exhibition spaces (especially non-art museums) need to be constantly updated to maintain, digital interaction and viewing experience are more suitable for this high-frequency update needs.

1. https://www.wpafb.af.mil/AFRL/

Fig.1.7: Children interactive, MICROPIA, ARTIS, Amsterdam, 2014
Source: https://www.micropia.nl/en/education/micropia-home/

1.2.3 From Tangible to Intangible

A few years ago, could you have imagined an empty table could be an exhibit for a non-art exhibition, not just a showcase? In recent years, especially after the widespread adoption of smartphones, more and more exhibitions have offered this new way of exhibiting a seemingly empty showcase that can be scanned by a mobile phone to present a deactivated 3D object on the phone that will respond to visitors' movements and rotations, a new kind of exhibition experience through the AR technology mentioned above. In fact, the table is not really "empty," except that the exhibits appear in an intangible (virtual) form, although from a spectator's point of view, the table is indeed empty. This intangible can be understood as an augmented space. The augmented space can be easily understood as a tool of "layers overlaying" where the extra layering information over the real physical space. *"Augmented space research gives us new terms with which to think about previous spatial practices. Before we would think of an architect, a fresco painter, or a display designer working to combine architecture and images, or architecture and text, or to incorporate different symbolic systems in one spatial construction, we can now say that all of them were working on the problem of augmented space. The problem, that is, of how to overlay physical space with layers of data. Therefore, to imagine what can be done culturally with augmented spaces, we may begin by combing cultural history for useful precedents" (Manovich, 2005)*[1]

1. Manovich, Lev. "The poetics of augmented space: Learning from Prada." manovich.net. p.13

Fig.1.8: Dinosaur Fossil Exhibition, Milwaukee Public Museum, USA, 2017.
Source: http://www.mpm.edu/

Tangible exhibits are flawed, including but not limited to transportation and space, and many large exhibits cannot be stuffed into a small, cramped space due to space constraints. Not to mention the physical exhibits that need security and maintenance, especially the precious exhibits (see Fig.1.8). Intangible mode or so-called augmented space could give some resolutions to this situation. With the help of equipment, it is possible to make many new changes to exhibits that have many limitations. For example, placing a large object in a small space (see Fig.1.9), or restoring a damaged building or sculpture to display its original

Fig.1.9: Concept of dinosaur in museum by AR mode.
Source: https://www.stambol.com/2016/12/19/ar-vr-museum/

style, or animating an otherwise still painting. Even more extreme is the idea that VR technology, using helmets or glasses to create a completely virtual space, and perhaps providing a new way for exhibition spaces, may be more intelligent.

1.2.4 From Parallel to Inclusion Relationship

In common speech, this kind of architectural space is called "empty." It is this "empty" that gives the exhibition space the possibility of placing exhibits. In a sense, this "empty" also provides the exhibition with space to put visitors of the possibility, that is, the visitors and exhibits are a juxtaposition-two-object under the "empty." However, this subtle logic seems to have changed as a result of this new technology, with previous exhibits becoming "empty" and users needing specific ways of interacting to turn "empty" into "non-empty," or visitors creating the exhibits. Then the original parallel becomes an inclusion relationship. In the traditional exhibition mode, visitors and exhibits are relatively independent. This means that the museum interior space provides a container that accommodates both the "exhibition" and the "visitor" elements. In this experience, the behaviour of the visitors will hardly have any different impact on the exhibits. Even interactive exhibits simply repeat several various pre-set operations.

Under the influence of emerging technologies, the relationship between visitors and exhibits may produce new changes. A scene in which the visitor dances to certain devices displays the dancer's renditions on a screen somewhere. With specific devices, such as motion capture technology, his movements can be projected onto the exhibit and become part of the exhibition, meaning that the viewer's role changes consistently as the exhibition progresses, from the visitor to the participant to the creator. This change has evolved the visitor's role from a pure participant in the exhibition to a communicator of the space. Even with the support of virtual technology, it may become a co-creator of the space.

Another exhibition space worth exploring is a domed space, which often appears in a hemispheric form (see Fig.1.10). The hemispherical space is used because it dissolves as much as possible the concept of walls and ceilings without dividing edges. And this space is commonly used in the projection technology. With this technology, the entire space will be built into a large environment depicted by a designer, plus sound and lighting, allowing visitors to enter the exhibits. At this time, the visitors are no longer parallel with the exhibits but become the core of the exhibits.

Fig.1.10: "TRANSITIONS by Panasonic Design", Milan Design Week, Italy, 2018
Source: https://www.panasonic.com/it/corporate/news/articles/panasonic-al-fuorisalone-2018-transitions-by-panasonic-design-palazzo-di-brera.html

VR technology is another extreme case. When users use VR technology, they will wear a helmet and completely isolate themselves from the existing space and enter an immersive virtual world which created entirely by the designer. The virtual world is the exhibit, which the author wants to convey. In this experience, the user will be surrounded by virtual exhibits, and the user is placed inside the exhibit instead of the parallel experience in the traditional sense. Although the virtual museum cannot totally replace the authenticity (worship value and representation value), the virtual museum still has its significance under certain conditions and produce new experience value.

1.2.5 From Possible to "Impossible"

Architecture is the art of space. In fact, architecture is an art based on physical construction. The built work could be the prerequisite for the discussion of space and architecture. Countless architects have tried a

Fig.1.11: Installation by Kengo Kuma Architects, "Sensing Spaces: Architecture Reimagined", Royal Academy of Arts.

variety of building materials and methods in order to place their artistic ideas and artistic expressions in spatial forms and experiences. This is often seen in exhibition spaces. Exhibition spaces often carry support for new technologies and new space system. Architects have more sufficient conditions to build their artworks. Pioneering architects often use the exhibition space as a test field for their own ideas. Here, architecture and space are pushed from impossible to possible, upgrade the entire space into a work of art from different aspects: such as materials, space experience, form, light, multi-dimensional sense and so on. For example, there is an exhibition named "Sensing Spaces: Architecture Reimagined" in the main Galleries of the Royal Academy of Arts; it considers architecture from the angle of the human encounter: how vision, touch, sound and memory play a role in our perceptions of space, proportion, materials and light (Fig.1.11).

Paradoxically, under the influence of virtual vision technology, this trend has completely reversed. In the past, architects tried to show design ideas and concepts to visitors through real construction. Now, through virtual experiences and enhanced exhibitions, architects and designers can convey their views directly to visitors in digital form.

Virtual vision technology provides sufficient technical support and theoretical possibilities for the generation of impossible spaces. In our case, Impossible spaces usually contain two aspects: one refers to the space that can be built in the real world, but cannot be realized due to the constraints of site or cost. On the other hand, it refers to space forms that cannot be built in the real world, such as the underwater world, aerial architecture, and so on. Based on the virtual experience and the immersion and interaction of the augmented exhibition, architects can no longer stick to the constraints of materials and mechanics. They can create more architectural spaces created by currently unachievable technical means. For example, As shown on the right (Fig.1.12), the dinosaur fossils and skeletons displayed in traditional natural history museums are difficult to present to visitors through powerful expressions. Even by restoring pictures or videos, they still cannot bring a high degree of immersion. However, with the help of VR technology, the designer "transformed" the entire exhibition space into an underwater world. At the same time, the fossils of ancient dinosaurs began to resurrect and jumped into the water from the exhibition shelf. This depth of experience and shock is unprecedented. The augmented exhibition brought by this virtual experience combined with the real exhibition venue is entirely new from the perspective of user experience.

Fig.1.12: Rhomaleosaurus: Back to Life in Virtual Reality, The Nature History Museum, London, UK

It is conceivable that with this "magical tool", architects and designers can boldly experiment with different forms of space and exhibition experience and apply this new trend to future museum design. Develop spatial patterns from possible to impossible.

1.2.6 From Static to Immersive

What is immersive space? The name is a metaphoric use of the experience of submersion applied to a representation, fiction or simulation. Immersion can also be defined as the state of consciousness where a "visitor" (Maurice Benayoun, n.d.[1]) or "immersion" (Char Davies, 1995)'s awareness of physical self is transformed by being surrounded in an artificial environment; used for describing partial or complete suspension of disbelief, enabling action or reaction to stimulations encountered in a virtual or artistic

1. The Navigation Room (1997, exhibition New Image, New Networks) and The Membrane (2001) were created for the Cité des Sciences et de l'Industrie in Paris. The Navigation Room, could be considered as the prototype of the interactive educative exhibition, deeply immersive, with highly personalized visits and content generating a web page dedicated to each visitor.

environment. The degree to which the virtual or artistic environment faithfully reproduces reality determines the degree of suspension of disbelief. The greater the suspension of disbelief, the greater the degree of presence achieved.

An immersive digital environment can be seen an artificial, interactive, computer-created scene or "world" within which a user can immerse themselves[1]. The most common way of immersive digital environment is Virtual Environment created through Virtual Reality (VR). As long as the user enters the digital environment and reaches the immersive state, whether it is a simulated real environment or a completely abstract fantasy virtual environment, it can be called immersive digital environment. Although the definition of immersion does not currently have a completely correct standard, it is generally believed that immersion is a subjective emotion that originates from the user itself. That is, users consider themselves to be part of the simulated "environment" or "space" of multiple elements (digital or physical) rather than the original space in which they are located. Whether users can be immersed in the digital environment depends on a variety of elements, including but not limited to images, sound, interactive devices and methods, entertainment, etc.

1. Joseph Nechvatal, Immersive Ideals / Critical Distances. LAP Lambert Academic Publishing, 2009, p. 48

In the context of architecture, immersive experience means creating a space that produces "illusions" that the visitor is ultimately transferred from one familiar environment to another. The visitor is isolated from the real environment by the space and various senses and then enters a "new" environment. In terms of museum space, this immersion means that visitors break the existing concept of traditional museum display and enter a new exhibition space created by designers and architects in the viewing experience. Here is an easy-to-understand example. When a visitor sees an animal model in a museum or sees a real animal in a safari park, neither of them is immersive. The reason is that visitors are clear about their willingness and environment. However, if the effect of being in the wilderness is created in a certain way in the museum, visitors will "mistakenly believe" that they are in the wild and interact with the "animals". This is an immersive experience.

From static exhibition space to immersive experience is the trend of the future exhibition space. Based on the development of visual technology simulation, Virtual vision technologies are taking the immersive experience to a new level. Virtual experience and augmented exhibition will become the primary way of immersive experience in museum spaces. Architects and designers can more easily create an immersive experience with these new tools. Visitors are also more likely to use and accept new technologies. How to adapt to this trend and whether the architect can use traditional space techniques to create a suitable exhibition space is facing architects and designers.

1.3 Augmented Space and Virtual Space

The accelerating technological development has made the public users accept new media and new technologies, which has led to the continuous increase of people's dependence on new technologies. This also means that architectural spaces, especially some cultural and public communication buildings represented by museums, also need to continuously upgrade themselves to meet people's familiarity and dependence on media and digital technologies. The widespread popularity of digital exhibits in museums has created the possibility of changes in museum space. Broadly speaking, any non-real element is digitally conveyed to users and belongs to augmented reality. Of course, this study mainly refers to giving visually additional information to the real environment. We can understand augmented space as adding a new layer in the real world, and this layer can be changed according to people's basic behaviour. The augmented space still relies mainly on the real space in the physical sense, but it only uses technical means to do some processing on the original space. Usually, this kind of processing is difficult to manufacture in the real environment, so architects and the designers will use this method to represent some space methods that are usually difficult to achieve in an augmented space.

A simple example is to simulate an exhibit such as a painting through AR technology through a smart device. In fact, the exhibit does not exist. However, human vision can be perceived, and this perception is infinitely close to reality (based on the high resolution of the retina screen, the performance of instant rendering, a gyroscope for vision and virtual Interaction of exhibits). The exhibits exist and are "seen" and "perceived" by the visitors.

If it continually increases additional information until all the real information is covered by virtual digital information. It will become a virtual space. In this case, it is generally necessary to use the VR helmet to assist in the implementation. Under the utterly virtual space, all the things that can be seen are computer-simulated. These analogue signals will make a series of feedback according to visitors' behaviour. In a completely virtual environment, the user's perception of the original space will change significantly. Usually, the mobile virtual reality device allows the user to move freely within a specific range. In actuality, the functions are often cautious, which is not fully immersed in the virtual world by the user's subconscious. They are worried that excessive movement will destroy the limitations of the original space. It puts new requirements for the designer, making this virtual space more natural in the original space, to eliminate this strange feeling brought to the user.

Different from the traditional exhibition mode, the change of the space brought about by the new technology also changes the interaction pattern of the user during the museum visit. The most significant change is the difference in the way of viewing. Herbert Bayer said, *"by means of movement of the eyes, of the head, or of the body, the field of vision is extended, it is also becomes larger with increasing distance between the eye and the object."* [1] If the object is converted to a virtual element, it is even a virtual space. This visually generated new interaction logic can make a huge difference to the museum space.

1. Bayer, Herbert. Fundamentals of Exhibition Design. New York: PM (Production Manager), 1939, 6(2): 17-25.

As shown in Fig.1.13, the revolution brought by technology has led to a change in the relationship between the user's vision and the exhibit. The left picture shows this relationship by Herbert Bayer in 1937. In an age when computers weren't born, it's hard to imagine 80 years later, when we used smart devices and used them to create virtual exhibits, we changed the relationship between users, exhibits, and space. The emergence of virtual exhibits breaks the relationship between the user and the object. Due to its characteristics, virtual exhibits can be moved with the user's behavior, rather than being fixed at a certain location, which directly changes the layout of the space. Augmented space displays virtual exhibits

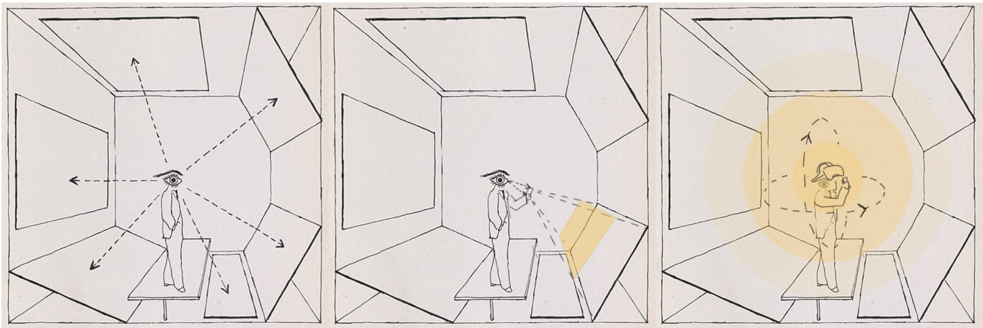

Fig.1.13: Vision in different means
Source: Made by author

through a mobile phone as shown in the above figure. At this point, the screen of the mobile phone is the booth, which is the carrier of the exhibit. Although the virtual exhibits can be large and the size far exceeds the size of the screen of the mobile phone, due to the perspective principle, the mobile phone screen can still be used as a suitable platform to support such large exhibits. Different from the traditional exhibition, the user's vision will be concentrated on the phone that is tens of centimetres away from the body instead of open vision. The situation of VR is different. In the VR context, all the virtual environments are the contents of the exhibits that the designer wants to convey. We will see different experiences in all directions, and vision will change from the one-to-one parallel relationship to Inclusion relationship.

The essence of space is to create boundaries with building materials or natural objects, which in turn creates a new spatial distribution. The emergence of virtual objects enriches the diversity of materials, and the use of virtual (digital) objects can also be used to divide and create space. This kind of digitized object also has more possibilities to transcend physical properties. It will create a new experience for designing different types of space, especially the space that is difficult to build with entities at this stage. This is why it can be used for design proposals as well.

1.4 Conclusion

Virtual exhibits and augmented space have presented as a solution for the future museum experience. With the support of technology development, we can improve the user experience when using augmented space and virtual exhibits in a low-cost development environment, even though the user experience is very different from the previous static display, whether it is from the users' behaviour feedback or the logical relationship between the user and the object. The experience upgrade brought about by this digital technological innovation is subversive. The exhibition and its space design need to pay more attention to visitors' experience during the exhibition. Architects need to present people's vision and expectations for future museums through architectural vocabulary, space creation and the convenience brought by digital technologies.

As Wendy E. Mackay said *"The most innovative aspect of augmented reality is not the technology: it is the objective. Instead of replacing physical objects with a computer, we create systems that allow people to interact with the real world in natural ways and at the same time, benefit from enhanced capabilities from the computer. "*[1] From the perspective of the space, how to adapt to the potential space change brought by the new technology, how can the space design give the user the better user experience, as well as design experience through technology? This is a new challenge for architects.

1. Mackay, W. E. (1998, May). Augmented reality: linking real and virtual worlds: a new paradigm for interacting with computers. In Proceedings of the working conference on Advanced visual interfaces (pp. 13-21). ACM.

1.5 Short List of Bibliography

1. Allen, Jamie, and Eleonora Lupo. *Representing museum technologies.* Politecnico di Milano, 2012.
2. Basso Peressut, G. L. and Clelia Pozzi. *Museums in an age of migrations: questions, challenges, perspectives.* EU-Polimi, 2012.
3. Bayer, Herbert. "Fundamentals of exhibition design." *PM (Production Manager)* 6.2 (1939): 17-25.
4. Davies, Char. *Osmose: notes on being in immersive virtual space.* Lisse, The Netherlands: Swets & Zeitlinger Publishers, 2002.
5. Heilig, Morton Leonard. "El cine del futuro: The cinema of the future." *Presence: Teleoperators & Virtual Environments 1*, no. 3 (1992): 279-294.
6. Mackay, Wendy E. "Augmented reality: linking real and virtual worlds: a new paradigm for interacting with computers." In *Proceedings of the working conference on Advanced visual interfaces,* pp. 13-21. 1998.
7. Nechvatal, Joseph. *"Immersive ideals/critical distances." LAP Lambert Academic Publishing* 2009 (2009): 14.
8. O'doherty, Brian. *Inside the white cube: the ideology of the gallery space.* Univ of California Press, 1999.
9. Ottolini, Gianni. *Forma e significato in architettura*. Laterza, 1996.
10. Maurice Benayoun. *"Interactive exhibition design."* Accessed April 21, 2020. https://benayoun.com/moben/bio/

CHAPTER 2

Augmented Reality, Virtual Reality and Museum Spaces

2.1 Introduction

In recent years, Augmented Reality (AR) and Virtual Reality (VR) technologies became more and more recognizable by the public, especially the leading technology giants, such as Apple (WWDC2018)[1] and Google (Google I/O 2018)[2], turned their market strategy to these technologies and made the related techniques more fluent in the practical use. Based on this context, AR and VR applications seem feasible and reasonable to support museum display and museum space design.

In terms of exhibition design, indeed, architects can be supported by AR and VR technologies in order to have an entirely new design experience and process. In traditional design methods, there are more or less

1. The Apple Worldwide Developers Conference (WWDC, also known as Dub Dub is a conference held annually by Apple Inc. in San Jose, California. Apple uses the event to showcase its new software and technologies for software developers. Attendees can participate in hands-on labs with Apple engineers and attend in-depth sessions covering a wide variety of topics.

2. Google I/O (or simply I/O) is an annual developer conference held by Google in Mountain View, California.

various deficiencies: for example, the paper drawings have the lack of a full understanding of the third dimension; computer modelling is mostly based on God's perspective, without showing the design logic on which the user's view is based; in the physical object the proportions cannot fully express the details and the materials characterizing the real scale. VR technology instead, thanks to the virtual space, can help architects to avoid these design deficiencies. Based on this virtual technology, the architects and users can be fully immersed in the accurate scale of the virtual space, while the space experience will be converted into the most intuitive visual sense, coupled with real-time rendering technology to assist the control of material, light, and other details, which can also be synchronized into the ideal environment.

2.2 Augmented Reality and Virtual Reality

2.2.1 Augmented Reality

2.2.1.1 Introduction

As it is defined in The Concise Fintech Compendium, *"Augmented reality is an enhanced version of the physical, real-world reality of which elements are superimposed by computer-generated or extracted real-world sensory input such as sound, video, graphics or haptics." (Schueffel 2017, p. 2)*

With the help of AR technology (e.g. adding computer vision and object recognition), the information about the user's surrounding real world becomes interactive and digitally tractable. Information about the environment and its objects is overlaid on the real world (an example described in Fig.2.1). As the figure explains, when people use a specific program to open the phone camera and capture the target picture, the

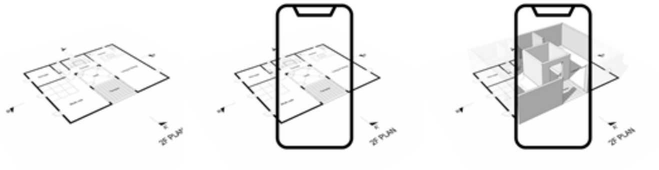

Fig.2.1: Image Identification AR diagram
Source: Made by author

screen simultaneously presents a new 3D model on the picture, which is prepared and recorded in advance into the smartphone application. This newly generated model is just like the real ones in this picture. When users move and rotate the picture's position, the model changes accordingly, based on the new position of the camera.

2.2.1.2 Historical Development

Regarding the history of AR, the earliest related descriptions may have started from science fiction. In 1901, L. Frank Baum wrote *“It consists of this pair of spectacles. While you wear them every one you meet will be marked upon the forehead with a letter indicating his or her character. The good will bear the letter 'G,' the evil the letter 'E.' The wise will be marked with a 'W' and the foolish with an 'F.' The kind will show a 'K' upon their foreheads and the cruel a letter 'C. Thus you may determine by a single look the true natures of all those you encounter.”*

More than 60 years later, the first AR device was actually created and used in 1968. Ivan Sutherland creates the first head-mounted display system. Since the equipment is too heavy, it can only be suspended from the ceiling. So this device has a nickname “Sword of Damocles” (Fig.2.2). Based on the core processing power of the computer at that time, the final result is a virtual cube, which will produce different instant perspective effects as the user’s movements.

Fig.2.2: "Sword of Damocles" by Ivan Sutherland
Source: Sherman, William R., and Alan B. Craig. *Understanding virtual reality: Interface, application, and design. Elsevier*, 2002. P.27

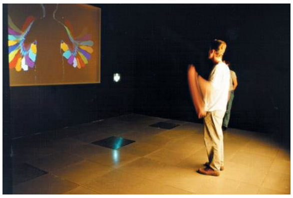

Fig.2.3: Videoplace by Myron Krueger, 1975
Source: http://www.inventinginteractive.com/2010/03/22/myron-krueger/

In 1974, Myron Krueger built an “artificial reality” laboratory called the Videoplace. In his laboratory, Two people in different rooms, each containing a projection screen and a video camera, were able to communicate through their projected images in a “shared space” on the screen. This can be seen as an interactive environment based on the virtual image created by users (Fig.2.3).

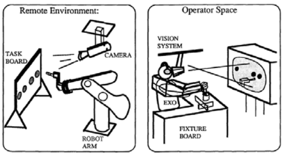

Fig.2.4: The first fully immersive AR by Louis Rosenberg

“Augmented Reality”, this word appeared the first time to describe the merging of virtual information on to a physical world by Tom Caudell in 1990. In 1992, Louis Rosenberg developed one of the earliest and the first fully immersive AR systems for the AR Force (Fig.2.4).

After nearly ten years of technological innovation, AR technology has evolved from a basic prototype to widespread acceptance and has begun to be widely used. Hirokazu Kato created the first open resource software library, ARToolKit[1] in 2000, and until now, this software is still active in various development platforms. Since Google announced google glass in 2014, all significant technologies have taken turns in turn, and have brought a variety of software and hardware related to AR. Today, users can easily make and interact with simple virtual items with these tools. Although we only have 50 years of development time (as shown in Fig.2.5), we have said goodbye to heavy equipment and improved the response speed and display effect so that it can be almost fake.

1. ARToolKit is an open-source computer tracking library for creation of strong augmented reality applications that overlay virtual imagery on the real world. Currently, it is maintained as an open-source project hosted on GitHub.

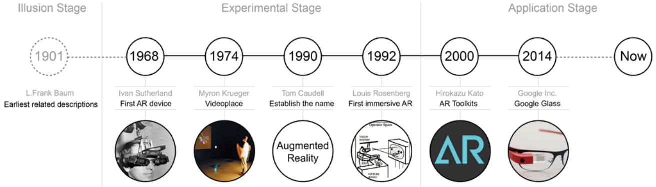

Fig.2.5: AR developmental History
Source: Made by author

2.2.1.3 Working Principle

In general, AR technology can be divided into two categories: object recognition and space recognition, based on where and when to display the virtual information. Object recognition, generally refers to when a camera or other image capture device discovery preset object (mostly will be a complicated picture), will set the virtual information which made by designers represented on the object. Space recognition, by means of the GPS system (which can also be fuzzily located in an area, such as an exhibition hall in a museum), the AR system is triggered when the user is at a particular location, at which point the virtual object looks for a suitable display space (usually some large and flat space) make the corresponding interaction.

For object recognition, in summary, the workflow of AR combined with architecture can be summed up as: 1. Identifying the target object (usually as an image); 2. Making three-dimensional models; 3. Importing them into unity engine production apps; 4. Debugging materials in unities and lighting, and eventually 5. Generating apps available on your phone (Fig.2.6).

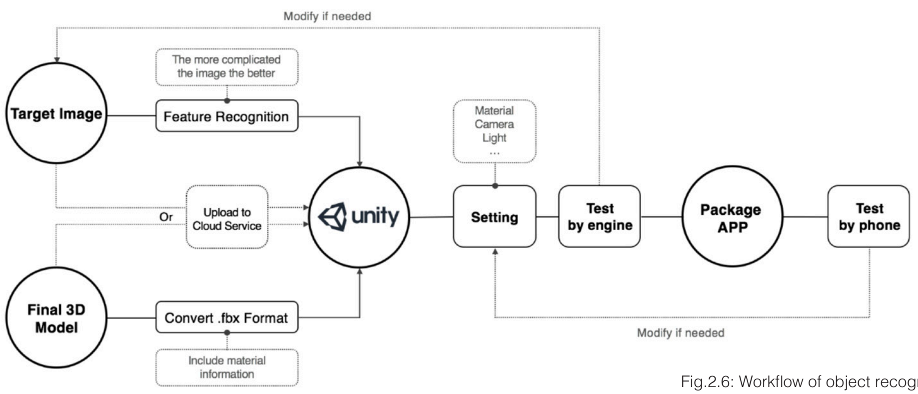

Fig.2.6: Workflow of object recognition AR mode
Source: Made by author

For space recognition, there is something different from object recognition mode: 1. Identifying target location through GPS (if want to use anywhere can ignore this step); 2. Making three-dimensional models; 3. Importing them into AR Kits production apps; 4. Setting the original plane (It is best to have a single color material and plane); 5. Debugging materials in unities and lighting; 6. Generating apps available on your phone (Fig.2.7).

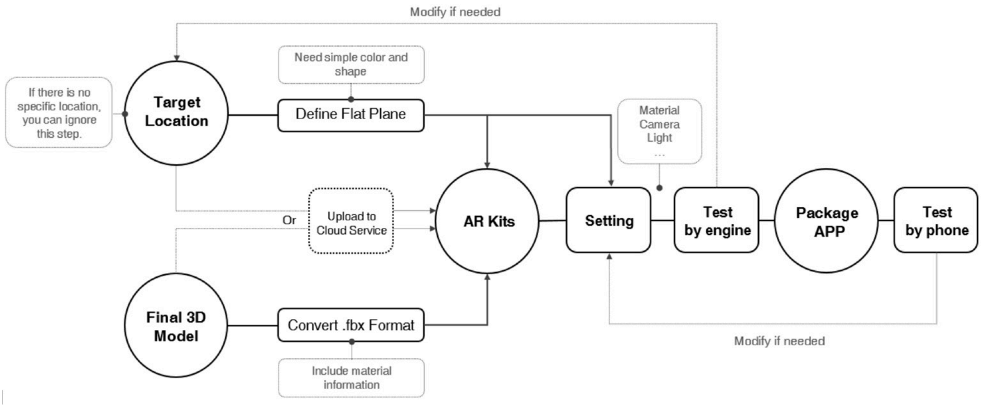

Fig.2.7: Workflow of space recognition AR mode
Source: Made by author

The AR in the process of combining with architectural perceptual experience embodies some advantages that traditional expression methods cannot have: real-time interaction with two-dimensional images and generation of three-dimensional models, and some basic ways of dynamic real-time interactions. However, AR technology may be constrained by hardware devices, both tablets and phones have border limitations: since the size of the screen limits the digital object representation, so that, even though a head-mounted device similar to HoloLens eliminates borders, the actual experience is not ideal; another one is that the need to achieve this AR experience requires the preparation of a corresponding three-dimensional model for different two-dimensional graphics in advance, and this upfront preparation workload is still enormous.

2.2.1.4 Demo Test

Concept:

From an architectural point of view, we try to generate a 3D digital building model based on a floor plan which can not only satisfy the correlation between 2D drawing picture and three-dimensional model, but it also achieves a new user experience which users can view virtual objects in real observation mode. Thus, the first demo we made is to test the above visualization result by AR progress.

Preparetions:

Hardware:

- Smartphone: in this demo, we use iPhone 7 Plus as test hardware.
- Computer: MacOS for coding.

Software:

- Unity 3D[1]: in this demo, we use Unity 3D as the main engine tool.
- Xcode[2]: for Compile the program to an application available on the iPhone

Database:

- 2D image: target image which will be replaced by 3D model
- 3D model: a simple building section model

Visulization:

During the preparation stage, we need to preset the target image and to prepare the 3D model of the virtual object. The purpose of the target picture is to generate a three-dimensional model that the user can recall when the phone camera captures the bi-dimensional picture. Because the phone camera analyzes all the

1. Unity is a cross-platform game engine developed by Unity Technologies

2. Xcode is an integrated development environment (IDE) for macOS containing a suite of software development tools developed by Apple for developing software for macOS, iOS, watchOS, and tvOS.

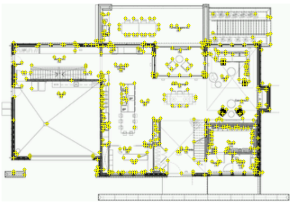

Fig.2.8: Feature points on target image
Source: Made by author

1. FBX (Filmbox) is a proprietary file format (.fbx) developed by Kaydara and owned by Autodesk since 2006. It is used to provide interoperability between digital contents creation and applications.

elements in its viewfinder range, there are enough feature points (as the yellow points shown in Fig.2.8) for the target picture, which cannot be too simple to elaborate. When you upload the target image, the system will determine if the image has enough feature points to support camera recognition. The more the feature points are, the easier is, for the camera, the correct identification of the related image. This means that the higher the complexity of the picture, the better the AR recognition of the pattern. Then, we prepare the corresponding 3D model and export it to the FBX[1] format, which is imported into the Unity3D software along with the previous target picture (Fig.2.9). In this demo, we need to set up the architectural model material and place the model on the related floor plan (target image). At the same time, we need to add an optical environment to ensure that the model can display the correct light and shade information.

Once these necessary preparations are ready, we can start packing them into apps available on your mobile phone system. Referring to our case, Unity3D has simplified the mainstream for smartphone, so that we could install the app on the phone with just a few simple steps (Basic functions need to be implemented with Xcode).

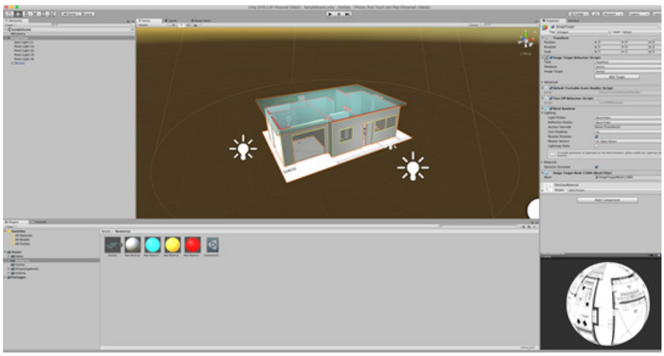

Fig.2.9: Work progress in Unity3D
Source: Made by author

Result:
Finally, we could test the demo with our smartphone. As you can see from the final effect shown in the Fig.2.10, a 3D model "grows" on paper through the screen. Once this floor plan appears on the phone screen, the previously designed three-dimensional model will be generated in its corresponding position, thus, achieving a three-dimensional (model feature) and two-dimensional (screen show) interactive experience. Of course, the model can be visualized from any point of view in the semi-space above the printed paper, from a certain given range of distances from it.

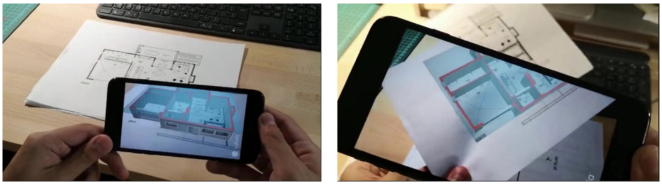

Fig.2.10: AR demo test progress
Source: Made by author

2.2.2 Virtual Reality

2.2.2.1 Introduction

Virtual reality (VR) is a computer technology that uses devices like glasses, headsets, or helmets, sometimes in combination with physical spaces or multi-projected environments, to generate realistic 3D stereoscopic images, sounds and other sensations that simulate a user's physical presence in a virtual or imaginary environment. A person using virtual reality equipment is able to "look around" the artificial world and, thanks to high quality VR, to move inside it and to manipulate there virtual features or items. The spatial simulation brought by VR technology Can restore the original appearance of three-dimensional space to the greatest extent, and can even accurately express the change of material and light and shadow based on realistic rendering technology. At the same time, this immersive experience based on VR technology is a panoramic experience In which the user does not only see the graphic information inside the frame, but is immersed in a complete, 360-degree digital environment, surrounded by a panoramic three-dimensional model.

2.2.2.2 Historical Development

The first VR device in the true sense dates back to 1956. Morto Heilig created a large machine named Sensorama[1], which can combine 3D video, audio, even smell[2]. This was done using scent producers, a vibrating chair, stereo speakers and a stereoscopic 3D screen. Heilig also patented the Telesphere Mask which was the first head-mounted display (HMD) in 1960 (see Fig.2.11). This provided stereoscopic 3D images with broad vision and stereo sound. There was no motion tracking in the headset at this point.

Same as previously introduced in AR part, Ivan Sutherland's "Sword of Damocles" also can be seen as the first virtual reality HMD (Head-mounted display), although this device is not suitable for wearing due to his weight.

VR devices are always pursuing real interactions between human eyes and electronic images, such as tracking eyeballs or head swings to change the corresponding position of the graphics. However, VR devices do not only have feedback on images and vision, but motion capture and interaction are also part of virtual reality. In1982, Sandin and Defanti created Sayre gloves to record and reflection the user's hands movements by using light emitters and photocells in the gloves' fingers (Fig. 2.12).

In 1986, Furness developed a flight simulator between

1. Heilig, M. L. (1992). El cine del futuro: The cinema of the future. Presence: Teleoperators & Virtual Environments, 1(3), 279-294.

2. The Sensorama was a mechanical device, which includes a stereoscopic color display, fans, odor emitters, stereo-sound system, and a motional chair. It simulated a motorcycle ride through New York and created the experience by having the spectator sit in an imaginary motorcycle while experiencing the street through the screen, fan-generated wind, and the simulated noise and smell of the city. These elements are triggered at the appropriate time such as the case of the release of the exhaust chemicals when rider approached a bus.The petrol fumes and the smell of pizza snack bars were recreated by chemicals.

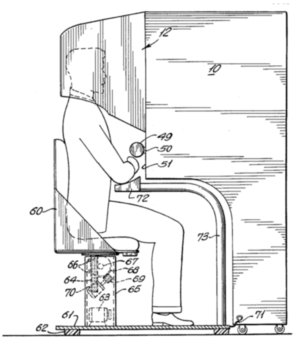

Fig.2.11: Illustration of Morton Heilig's Sensorama device.

Fig.2.12: Feature points on target image

1986-1989 known as the Super Cockpit[3]. The training cockpit featured: computer-generated 3D maps, advanced infrared and radar imagery and the pilot could see and hear in real-time (Fig.2.13). Famous game company Nintendo launched the Virtual Boy console which played 3D monochrome video games. It was the first portable console to display 3D graphics in 1995. However, limited to display functions, this product has not achieved previous results.

Till now, many companies are developing VR products, hardware and software. The best known and the first to succeed in the commercial sector is HTC VIVE headset (Fig.2.14) with sensor-based tracking which allowed users to move freely in space. With the development of technology to this day, the development of VR has made the equipment smaller and smaller, and the feedback has become more and more accurate. VR headsets are not only becoming lighter and lighter today but also providing more degrees of freedom, fewer wires (even wireless devices), more powerful processing power and more intuitive operation methods. This has gradually moved VR games from hardcore players to many mild players. Many users are not loyal fans of video games but attracted by their exciting content and immersive experience. Because of this, the development of VR software not only focus its application on video games but also various VR applications (such as chat, video browsing,

3. Furness III, T. A. (1986, September). The super cockpit and its human factors challenges. In Proceedings of the Human Factors Society Annual Meeting (Vol. 30, No. 1, pp. 48-52). Sage CA: Los Angeles, CA: SAGE Publications.

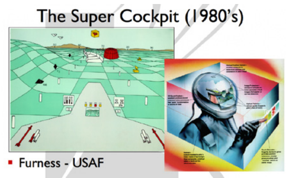

Fig.2.13: Furness III, Thomas A. "The super cockpit and its human factors challenges." Proceedings of the human factors society annual meeting. Vol. 30. No. 1. Sage CA: Los Angeles, CA: SAGE Publications, 1986.

Fig.2.14: HTC VIVE headset

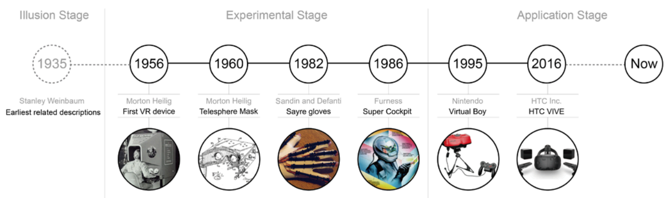

Fig.2.15: VR developmental History
Source: Made by author

etc.) and application scenarios (museums, school education, office meetings, etc.). Due to the limitations of display technology and computing power, the current VR does not exert the best expected effect. With the development and improvement of technology, imagination and creativity will become the core conditions for virtual content.

2.2.2.3 Working Principle

There are two types of VR widely using in museums, static VR and interactive VR. Static VR only plays spherical images or videos to users through VR glasses. To achieve this type of visual simulation, it is necessary to prepare the three-dimensional whole model of the space in advance, supplemented by certain rendering techniques to enhance its realism. In this research, we have chosen to use static VR, that is, a purely visual type of VR, where the user is not free to move within the given space. We selected some relevant viewing points in this model and rendered 360-degree panoramic images based on those camera points. Once we got the mentioned images, we could import them into a VR equipment (VR glasses through phone in this case). With VR equipment, users can then enter and experience the 3D dynamic visual perception of the space we simulated at any time. In a dynamic virtual reality experience, users can walk freely in a virtual space created by the designer. Equivalent to each move, and each new postion of the user, the system will render spherical images in real time.

In terms of workflow, as illustrated in the Fig.2.16, as long as the designer completes a complete model and sets the position of the camera, s/he can complete a VR picture with the help of a renderer. If further developments are required, interactive designs can

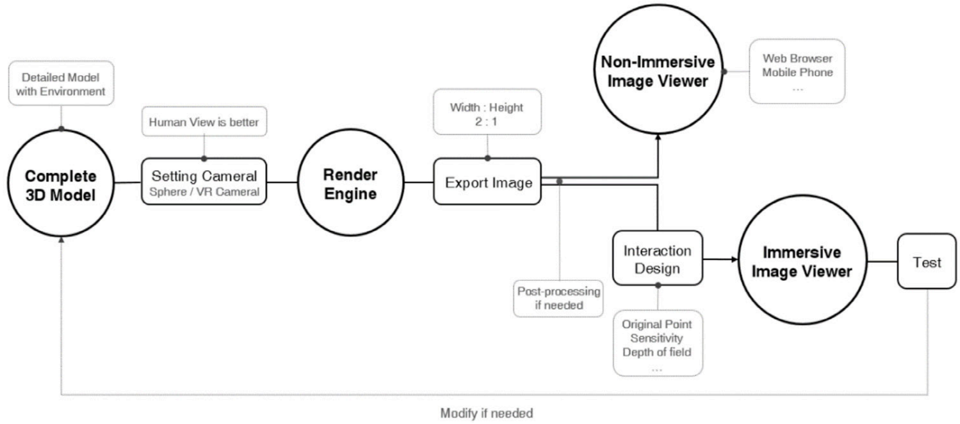

Fig. 2.16: Workflow of Static VR
Source: Made by author

also be carried out through other software programs to complete the movement, to transform the scene, and even to simply interact with the objects placed in the scene. The principle of spherical video is similar, except that a special lens is used to form a continuous picture into a video picture. Of course, we can also use a special camera to record or photograph the material directly in the real world.

Interactive VR is much more complicated than static VR (as seen in Fig.2.17). First of all, from the 3D model preparation stage, since the interactive VR allows the user to freely explore and move within a certain range, the model must be constructed in strict accordance with the requirements of the engine software. Next, it needs to set the interactive elements, such as where to enter, where to trigger the corresponding action, which is also designed to match the sensor's related functions. The enhanced interactivity can give users more choices. Users not only observe digital exhibits through visuals, but also experience virtual exhibits through mobile, games, and even collaborate other users. So the experience design in interactive VR mode is very important, to a certain extent, it determines the key factors of whether this virtual exhibit can successfully attract users and convey the intentions the designer wants to represent.

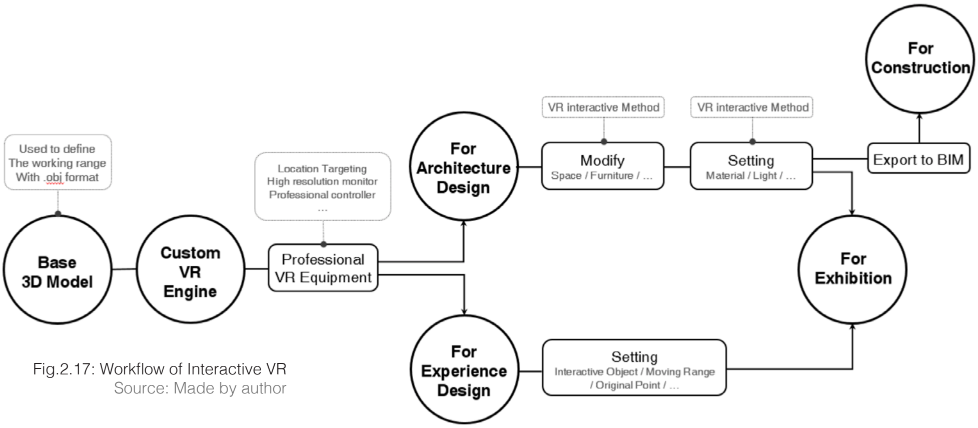

Fig.2.17: Workflow of Interactive VR
Source: Made by author

2.2.2.4 Demo Test

Concept:
In this test, we tried to create a fully enclosed room model, through VR rendering technology, enabling users to view the interior rendering experience in an immersive method through VR glasses and smartphone.

Preparations:
Hardware:
- VR glasses: In this case, we use Google Cardboard[1] as a low-cost auxiliary display device.
- Smartphone: Mainly through mobile phone screens and sensors to present the final result
- Computer: For rendering image and 3D model

Software:
- Sketchup[2]: For build 3D model

1. Google Cardboard is a virtual reality (VR) platform developed by Google for use with a head mount for a smartphone. Named for its fold-out cardboard viewer, the platform is intended as a low-cost system to encourage interest and development in VR applications.

2. SketchUp, formerly Google Sketchup, is a 3D modeling computer program for a wide range of drawing applications such as architectural, interior design, landscape architecture, civil and mechanical engineering, film and video game design.

3. V-Ray is a computer-generated imagery rendering software application developed by the Bulgarian company Chaos Group, that was established in Sofia in 1997. V-Ray is a commercial plug-in for third-party 3D computer graphics software applications and is used for visualizations and computer graphics in industries such as media, entertainment, film and video game production, industrial design, product design and architecture.

- V-Ray[3]: For render image

Database:

- 3D Model: A closed and complete model

Note:

- 3D Model could be done in almost every 3D platform software including but not limited to Rhinoceros, 3dsMax etc.

Visulization:

VR technology is a panoramic experience in which the user does not only see the graphic information inside the frame, but is immersed in a complete, 360-degree digital environment, surrounded by a panoramic three-dimensional model. Compared with the traditional perspective image, the VR image uses the spherical coordinate system. Then, a panoramic picture in this system, normally works as shown in the following images.

In traditional rendering, we usually only need to render objects that can be seen in the range of view chosen. Compared with the traditional rendering method, making a VR panoramic picture rendering requires the establishment of a complete 3D model, rather than just the portion of a model that the lens can see under a specific visual angle. During the rendering process, it has to be used a spherical camera the aspect ratio to 2:1 has to be set, in order to ensure that the horizontal view is a 360-degree view and the vertical view is a180-degree one (as seen in Fig.2.18). In order to have a more immersive experience for the user, it is

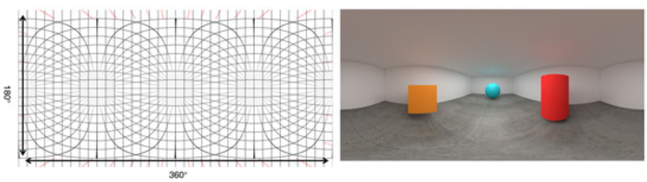

Fig.2.18: VR test room
Source: Made by author

Fig.2.19: VR test in glasses and in normal view
Source: Made by author

recommended that the height of the camera be set to an altitude similar to that of the human eye (normally about 1.6 m from the floor level).

Result:
Finally, we can get a VR image which has the aspect ratio in 2:1. We put this image in smartphone, and use Google Cashboard VR mode, then the phone screen will divide it two parts achieving the depth of field 3D effect of the left and right eyes (as shown in Fig.2.19). When we put this VR glasses on our heads, we can enter the immersive experience. When we turn the head, the picture will change accordingly.

2.2.3 Comparative Study
2.2.3.1 Basic Theory
Both Augmented Reality and Virtual Reality are essential processes that use digital technology to create virtual objects. Both have similarities such as equipment and their working principle. Their ultimate goal is to give users a more realistic experience. This reality is simulated by computer, and the virtual exhibits can also have some physical states that are difficult to reach in the real world. This critical thinking about reality and virtuality is a fascinating state.

VR is an interactive virtual environment; AR is a real-world environment “augmented” with virtual objects. Both got their start in the 60s and were developed simultaneously. AR can be thought of as a close relative of VR. Although technology and applications are different for each, they often work hand-in-hand. Both can be considered to be “artificial realities”.

The critical difference is that VR replaces reality and creates an immersive artificial world while AR overlays virtual objects on top of the real world. It’s important to note that VR and AR both use unique technologies, we won't get into the nitty-gritty, but suffice to say you can run both types of programs on your phone, but they don't use the same algorithms.

On the one hand VR and AR are two different things, on the other, we can think of them as two different flowers on the same plant. They are both attempts to allow us to better interact with our environment by using virtual information. Many devices support both types of tech.

For easily understanding, we can image that point R0 is the reality which we can see. Make R_0 as the origin, to the right extension; we have an axis named reality-virtuality continuum. The scale on the number axis represents how much of the digital information we put on the naked eye (Amount of Augmentation). After the show in our eyes after the picture is to enhance reality. When the scale on the number of continuous increase, we will be farther and farther away from R_0. Ultimately, we will get an extreme situation, that is virtual reality. In this distance from the R_0 infinity, our naked eye screen is completely covered by digital content. The reality of things and our eyes are irrelevant. Therefore, VR is a point on the AR axis, which is an extreme case of AR.

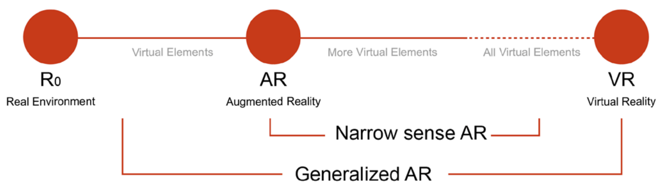

Fig.2.20: AR and VR diagram
Source: Made by author

2.2.3.2 Experience Report

Context:

Augmented and Virtual Reality are the two technologies, both have the remarkable ability to alter our perception of the world. But while AR and VR have a lot in common, they could also lead us down totally different paths in entertainment, designing, communication, and moreover, in my study of immersive experience in the museum. Thus, in order to gain insight into the different experiences between AR and VR and the possibility of using them in the exhibition space, I visited a company which is specialized in these two technologies in China.

When I approached the experiences, I had several specific goals in mind:

1. The technologies seem widely developed in big digital and smart technology company such as HTC, Samsung, Apple, and Microsoft, I was curious about how the SME company develop the augmented and virtual reality equipment as well as the related software.
2. I know that the technologies are popular in China, I was willing to visit a Chinese company to understand how they practice the technologies in the architecture and exhibition field.
3. During the experience, I wanted to analyze both the positive and negative points of these two technologies and extract the core values of using VR and AR in the immersive space.
4. Additionally, I wanted to understand the models used by the two technologies and future study about how to develop and improve these kinds of techniques in order to use them in exhibition space.

Background:

- Experience Location: Shanghai
- Experience Date: 25/08/2017
- Technical Support: SheenCity[1]

1. http://www.sheencity.com/

AR Experience:

- AR Platform: SheenCity AR Beta Version (For Android)
- AR Device: HUAWEI mate 9

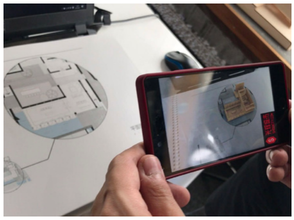

Fig.2.21: AR Experience
Source: Photo by author

Fig.2.22: VR Experience
Source: Photo by author

In the AR experience, we enjoyed a collection of architectural works in a new way. Through the phone screen, we can see some enhanced information appearing on the original paper portfolio. For example, on paper media, an ordinary black and white hand-drawn pattern, through the AR technology, displays colored hand drawings on the phone. Or, like the previous demo, a floor plan is displayed as an architectural model by AR.

It is also very easy to learn how to operate and the experience process has no additional requirements for space. After a brief explanation by the staff, we can operate it on the mobile phone. It can even be said that, given the use of mobile phones in daily life, we can successfully complete our experience process even without the explanation of the staff.

The experience is wonderful during the browsing of the entire portfolio. We will look forward to what changes on the content of the next page will be represented on the mobile phone. Through the mobile phone or the user's own movement, observing the changes in the model in the mobile phone gives the user a high desire to explore. Compared with the traditional models and drawings, we are more willing to use new methods to observe and meet the goals that the designer wants to convey.

From my personal perspective, this AR experience is a successful example that show us how the AR as a tool in architectural representation. It also gives us an optimistic attitude towards its applications in museums.

VR Experience:
VR Platform: SheenCity Mars Ver. 1.30
VR Device: HTC VIVE

This experience is my first full experience of the full set of HTC VIVE equipment. The VR put me in a model that has been present in the computer (in this experiment we chose the classical model of the German Pavilion at the Barcelona Expo), I could walk in the experience (can be achieved through real walking and also be implemented by operating the controller). As if walking in a real German pavilion, real mobile feedback and visual experience did provide a virtual space and successfully "cheat" the brain. In addition to the basic mobile and browsing features, I also tried some other features: such as placing furniture, vegetation, modifying materials in the model, lighting, and more. These undoubtedly gave the architect more help in architectural design.

Much different from the AR experience, the installation of the device takes a relatively long time (5 mins). It takes a certain amount of time to wear the helmet, especially for people like me who wear glasses. Although glasses can still be used, the shape of the glasses is different, and it is inevitable that the helmet may be uncomfortable when using the helmet. Another thing that has to be mentioned in the learning process. Since every VR program is different, if there are complicated operations in it, then the staff needs to patiently explain. The user needs a certain amount of time to understand and adapt to this operation mode. For those who don't often play game controllers, these operations seem to be very difficult to learn. From the user experience point of view, it seems that VR, which is only used for viewing or simple operation, is more suitable for a temporary short-lived as a new browsing method.

Overall, observing the virtual world through VR is a very novel experience. Through visual technology, users are completely exposed to an immersive world. There is some strange experience with the isolation from the real world. However, at present, this kind of experience is not recommended for long-term use, which may cause headaches, dizziness and other adverse reactions for users.

As an emerging product in the digital age, AR and VR have many application areas and meanings: in addition to commercial applications, the use of new multimedia devices, a fusion of gameplay and entertainment elements, AR and VR have promoted the spread of culture to a certain extent And development. At the same time, the appeal of these applications to young people is enormous, which means that AR and VR will make outstanding contributions in the field of education.

2.2.3.3 Comprehensive Comparison

After preliminary research and physical experience, we found that AR and VR have similarities and differences in principle and application. For its application in space, I listed the following parameters to make it easier for us to understand AR and VR.

Key parameters:

- <u>Demand of minimum space size:</u>
  Different technologies have certain size requirements and restrictions on space, even the shape of space.
- <u>Change of the original space:</u>

In order to introduce an immersive experience brought by new technologies, it may be necessary to make different changes to the original space.

- Spatial form of demands:
  The requirements of different technologies for spatial forms involve the spatial relationship between different users.
- Ratio of virtual and real:
  The proportion of virtual exhibits in the experience process, as well as the scope of influence of virtual exhibits.
- Basic devices:
  Basic equipment used in the experience process.
- Ratio of equipment to number of users:
  The relationship between the number of devices and the number of users simultaneously, and their relationship in different space.
- Best use time:
  Different time will bring different depths of immersion, but due to the limitations of the device, the long time will affect the user experience.
- User learning time:
  Users need extra time for new devices to familiarize themselves with and learn how to use.
- User immersion:
  The degree of immersion users get from the augmented environment brought by different technologies.

In this regard, I made a table (as shown in Fig.2.23) that compares these parameters with different techniques. Based on these comparisons, I summarized the following results: The interactive mode VR can give users most immersion, and the screen effects and visual experience are the best of the several different enhanced augmented experiences

	AR Object Recognition	AR Space Recognition	VR Static Mode	VR Interactive Mode
Demand of minimum space size	2-4m^2 /person	2-4m^2 /person	1-2m^2 /person	10-20m^2 /person
Change of the original space				
Spatial form of demands	target object	flat space simple material	isolated space	isolated space big size space for sensors
Ratio of virtual and real	Virtual Real	Virtual Real	Virtual Real	Virtual Real
Basic devices	Smart Phone	Smart Phone	Smart Phone + VR Glass	Smart Phone + VR Glass + Controller
Ratio of equipment to number of users	Space user device	Space user device	Space user device	Space user device
User learning time	less than 1 min	less than 1 min	1-2 mins	2-4 mins
Best using time	2-3 mins	2-3 mins	3-5 mins	10-15 mins
User immersion	lower	low	medium	high

Fig.2.23: AR and VR comparison table
Source: Made by author

mentioned above. However, this technology also has the highest space requirements. Due to the virtual and immersive experience of VR, users need to act in an independent, safe, and large enough space. In contrast, static VR only needs to let the user view the content in the glasses. The type of AR is relatively small due to the convenient operation and portability of the device. From a technical point of view, the space requirement is relatively small. Space recognition type AR requires the original space to maintain a simple material and flat, while the object recognition type AR does not have any additional requirements.

2.2.4 Applications in Other Fields

In addition to being the main augmented space tool in the exhibition space, AR and VR have a wide range of applications in architecture. First, as an application in the field of architecture representation. As we already know from the digital era, indeed, architectural representation is an indispensable operational means during the architecture design process stages, not only for architects but also for clients and construction workers. Traditional architectural representations such as sketches and solid models are the most Today, designers and architects have more efficient ways to depict their ideas thanks to the explosion of digital technology which brings us computer-aided drafting, photo-realistic rendering, as well as augmented reality and virtual reality to support architectural design and architectural visualization. Decades ago, realistic images with precision perspective, lights and shadows, and materials simulations, were the height of aspirational innovation. Nowadays, in the digital age, we can make a beautifully rendered picture effortlessly with software. Sketches and 2D Drawings as the most fundamental architectural representations, allow gran in order to meet the needs of the modern production, the development of computer technology such as BIM systems can assure that the accuracy of the two-dimensional drawings, directly generated from the 3D Models, better serve the entire building design procedure. On the other hand, the progress of digital image processing brings another advantage to architectural representation. Based on the simulation of rendering technology, designers can better control the design and refine the materials, lights, and shadows, through timely feedback of computer images to test the possible final perceptual impact of the building. Even though these three-dimensional images are still presented in a two-dimensional plane, that is, a screen or a paper. In this context, thanks to the popularity of smart devices making augmented reality and virtual reality of more practical use, a new opportunity has emerged for architectural representation: the immersive experience. Due to the real-time feedback on user behavior and interaction, it combines virtual space with the real space, providing a new experience for architectural representation and design.

People can also use VR and AR applications in architecture education, including descriptive geometry education and three-dimensional composition education. Concerning descriptive geometry, as we know, it allows representation of three-dimensional objects in two graphic dimensions, by using a specific set of projective procedures. One scope of traditional descriptive geometry was and still is, indeed, supporting the understanding of the spatial properties and relations, which for a student in architecture is one of the most relevant educational goals, that is, in order to make students able to figure out and control the architectural space starting from planar images set as graphic projections of spatial configurations. Since the students are in the primary stage of architectural space, their perception of space does not have a profound experience and understanding. With the help of virtual vision technology and equipment, they can better experience the space, especially regarding the changes in the feeling of the space under the change of various parameters (size, material, etc.)

In the construction of the building, AR and VR can also provide a lot of useful help in the new era. Through AR and VR technology, the construction personnel can find the construction location more accurately, especially for those non-linear constructions, the logic of each different components is very complicated. It helps workers install equipment efficiency through the feedback of AR and VR, which can provide installation information (component type, size, position, etc.). With the aid of AR and VR, this technology can help workers accurately complete their work in the face of complicated pipeline installation. At the same time, portable network and visualization can also help architects and designers to participate in the construction and solve problems encountered in construction in real-time.

2.2.5 Conclusion

Due to the development of technology, techniques such as AR and VR technologies as well as computer-aided modeling, parameterization, and computer rendering, are promoting an emerging impact on virtual exhibits and exhibition design. However, in real practices, there are few key Issues and challenges that need to be identified for prospective future researches.

1. Although AR and VR have changed visitors' viewing habits and interactive experience to a certain extent, their changes to physical spaces are still limited in the current technological environment. Relying on the traditional exhibit and museum design, AR and VR can only make simple independent modifications. More complex structural modifications still need the assistance of traditional browsing and space design method.

2. Since the interactive methods are currently not uniform, there are many limitations in using these two techniques. For example, installation and software support for VR devices is relatively cumbersome and requires high operating space, while AR handheld devices are also limited by the standard display ranges, and this also affects the experience.

3. Compared to AR technique, VR devices need to have some preparation time before starting a fully

immersive experience, i.e. for installing devices and learning how to use them, and this currently makes hard to achieve high-precision operations through interactive devices.

2.3 AR and VR in museums

2.3.1 Introduction

Every innovation in vision technology will bring new changes to the exhibition. New technologies bring a new spatial form from the display equipment, exhibits, exhibition methods, and even user experience. As a display-oriented type of architecture, the museum faces new technologies, uses these visual technologies, and brings a more immersive user experience to the audience is a new challenge for museums. In addition to the technical challenges, the trend from tangible exhibits to intangible exhibits, the new experience brought to the user, and the original space's combination is an unprecedented new problem for architects and designers.

Technically, AR and VR can be described as a new type of screen. This screen is different from traditional video playback. The AR and VR screens are closer to the user and have their own characteristics. For the museum's design, in the past, we may need to leave enough space for the larger screen, but the appearance of AR and VR can complete the significant screen experience without taking up much space. Through AR and VR, architects can also digitally create an immersive space. Here, designers can use digital methods to build this space without having to build it physically.

Spatially, the original site has been digitally processed to create a new spatial form, augmented space through AR and VR. With virtual objects, the augmented space creates a space effect that traditional architects cannot create, which can change the world's gravity and add complex light and shadow effects. Unlike traditional space construction, the virtual space uses the virtual object as the material to complete the construction. This construction can be combined with the original space. Of course, VR can also be used to realize the completely virtual space to achieve a completely immersive state.

In terms of space experience, the emergence of new virtual elements gives users a completely different experience than traditional digital elements. Digital elements are not new in museums, such as projections and LED screens to provide virtual digital elements. However, these traditional digital elements do not bring about substantial spatial changes. The most fundamental reason is that these elements cannot provide the entire interactive feedback system. AR and VR provide this new experience based on real interactive logic, just like a virtual object in the real world. There is a problem here: In the museum dominated by visual observation, there is now a virtual object. This virtual object can completely achieve the degree of falseness in a visual sense. Is this virtual object still virtual?

In the museum framework system, vision is undoubtedly the most important means of observation. AR and VR provide this new way to change the space and even change the interaction logic. For different types of museums, AR and VR have different focuses in the process of use. Depending on the type of museum and the requirements for user experience, AR and VR also have different strategies and content in their applications.

2.3.2 Mass Basis

In order to study the current status and public acceptance of AR and VR in the museum, I launched a survey questionnaire for ordinary visitors. (See Appendix for details of the questionnaire). The questionnaire aims to understand the general public's understanding of AR, VR and its application and prospect in museums. The subjects of the survey are Chinese people, most of them are undergraduates and above, and many people are engaged in design-related fields. The interview was completed via the Internet. A total of 153 questionnaires were distributed. The survey questionnaire consisted of 11 multiple-choice questions and two essay questions (optional). In the final, 122 valid questionnaires were collected. Despite the limitations of the sampling object, the results are still of general significance.

Based on the survey data, we can see that most people have a basic understanding of AR and VR (as shown in Fig.2.24). Although the commercial popularity

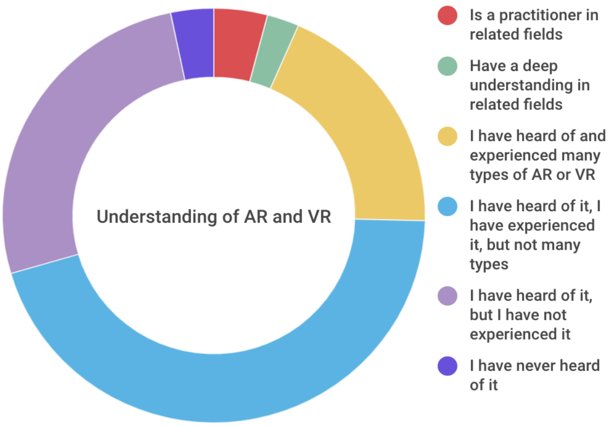

Fig.2.24: Data analysis for AR and VR popularity
Source: Made by author

of AR and VR has only been a matter of recent years, most people have used related equipment, which provides a sufficient mass base for this research.

Two other essential questions asked the public about the degree of acceptance of interactive and virtual exhibits. According to the results, the vast majority of users are highly accepting of interactive exhibits and virtual exhibits, and are willing to try new ways of the exhibition.

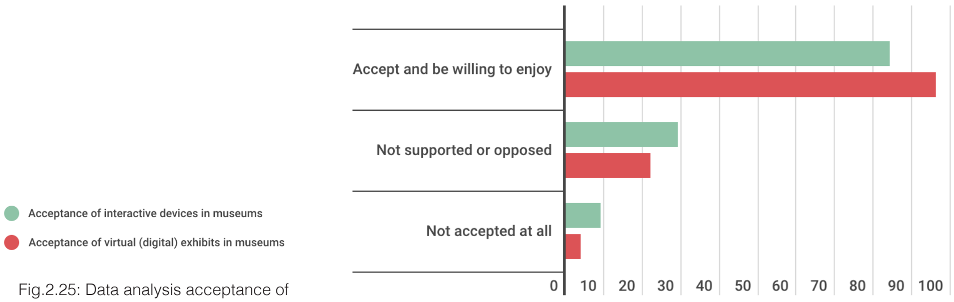

Fig.2.25: Data analysis acceptance of interactive devices and virtual exhibits

In this survey, I also focus on AR and VR applications in different museum types, and some exciting results were obtained. The art museum is the most popular type among all museums, which reflects the increasing public demand for the appreciation of works of art and the high aesthetic appeal of the public. AR and VR are the representatives of emerging technologies. In the "The most suitable museum for AR and VR" issue, it is not surprising that the Science and Technology Museum is at the top. The choice of the museum of ruins is quite surprising. As the data shows, the site museum is not a popular choice, and in the "The most suitable museum for AR and VR", the site museum ranks second, reflecting If more AR and VR technology is used in the site museum, it will bring more vitality and attract users to visit. How to make the museum

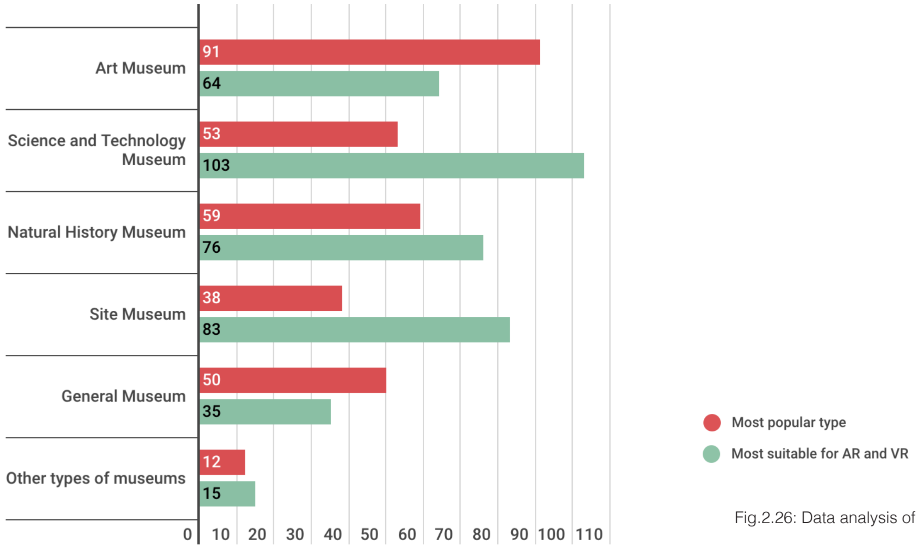

Fig.2.26: Data analysis of museum types

more attractive and show the exhibits to the audience through a combination of technology and space design is a challenging topic.

On the level of user viewing experience and museum space usage, I asked if AR and VR would change the traditional viewing mode and museum space design. From the data feedback point of view, only a minimal number of people think that it has not changed for our current exhibition mode and space design. Most

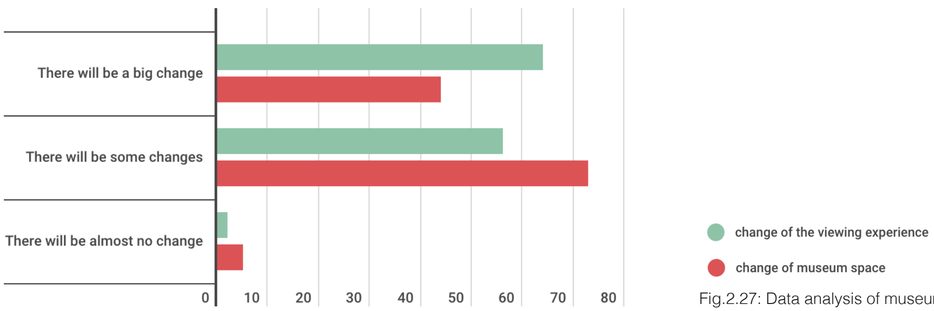

Fig.2.27: Data analysis of museum changes

people have a positive attitude towards the application of AR and VR in museums. Although there are different understandings of how much has changed, it is undeniable that these new technologies will be a new topic for both the change of the exhibition mode and the change of the museum space design.

Nearly 90% of respondents believe that AR and VR will appear more in museums and exhibition spaces in the future. This shows that people's attitude towards virtual vision technology is positive and willing to experiment. The impact and response of new technologies provide motivation for research, and users' attitudes can help research to proceed more easily. I also collected the textual information of the respondents' advantages and disadvantages about the use of AR and VR in the museum and summarized them into a word cloud. The deeper and broader the font, the higher the

Fig.2.28: Words cloud of advantages

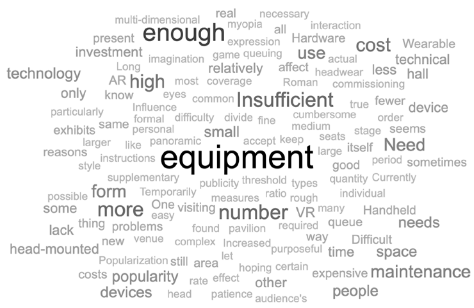

Fig.2.29: Words cloud of disadvantages

frequency of the text. From the statistics of the word cloud (Fig.2.28 and Fig.2.29), the advantages that the public provides for AR and VR are immersion and new experience. Interaction is another vocabulary with a high frequency of appearance. Based on the characteristics of high interactivity, AR and VR can provide more possibilities for museum space. In the collection of questionnaires for their shortcomings, many users have more questions about the equipment, including maintenance, security, cost and how to use it. If these concerns can be given full consideration in space and product design, they should be able to effectively alleviate public concerns. Others have different views on the different experiences brought about by the originality and the virtual effects. These problems are urgently needed to be explored and studied in the museum space and virtual exhibits.

As shown in Fig.2.26 on the previous page, this article will focus on three types of museums. The selected categories are: as the most popular type "art museum", the most suitable for the use of AR and VR "science and technology museums" and the maximum contrast questionnaire answer "site museum".

2.3.3 Science and Technology Museums

The Science and Technology Museum is arguably the best platform for new products, especially for technology. As a new technological product, VR and AR can be used in the Museum of Science and Technology as an exhibit of the Internet era, from software to hardware. In the future, these essential devices which provide people with a purely virtual world will become important historical objects, which represent a milestone in the development of science and technology. Of course, in the Science and Technology Museum, VR and AR are more of a tool or medium to help users get a better experience.

Texts and images may be the most common exhibits in the Science and Technology Museum, and this traditional way of the exhibition may not sufficiently bring an immersive experience. In the museums with many exhibits, the annoying texts and pictures are difficult to read and understand for a long time, making it challenging to convey the content that needs to be expressed to the readers, especially the scientific and technological content dominated by rational thinking. The Science and Technology Museum also carries a crucial educational significance, especially for children and adolescents. Science and technology museums are often the keys to children's desire to explore the world of technology. However, in the Internet age, people can easily acquire a variety of knowledge from all over the place, not just schools and museums. Then, for science and technology museums, they are faced with the impact of technology, how to continue staying vitality and more efficient, more accessible, and more attractive to the user, will be the challenge of the future technology museum.


Fig.2.30: Uers in Science Museum of UK

The mature application of VR and AR technology provides a new form of representation for museum space and exhibits. AR and VR provide not only high-definition 3D models, but also real-scale virtual scenes and game elements that interact with real-world scenes, which will undoubtedly significantly increase the appeal of the exhibits, especially for children who are the essential target customers of the Science and Technology Museum. For example, in Science Museum of UK there is an exhibition named "space descent VR with Tim Peake" [1]. Visitors can use VR technology to get a 360° look inside a Soyuz capsule and experience the thrill of being an astronaut (Fig.2.30). In the virtual

1. https://www.sciencemuseum.org.uk/see-and-do/space-descent-vr-tim-peake

world, visitors will be in a spaceship and enjoy the vast stars 400 km away from the Earth. After seeing this exhibition, Tim Peake[1] said: *"It really is breathtaking—and that comes from someone who has spent an awful lot of time using VR systems while training for my first mission. Science Museum visitors are going to experience something that truly is very close to the real thing!"* Through the virtual space, visitors can easily follow digital technology to anywhere, without space constraints, without financial constraints, experience rocket launches in a dynamic environment, and observe the universe. This experience and effect are far better than the model of a spaceship or a video of the universe. Based on the above description, the changes brought by AR and VR in the Science and Technology Museum are apparent. The author believes that this will mainly bring about several changes.

1. Major Timothy Nigel Peake CMG (born 7 April 1972) is a British Army Air Corps officer, European Space Agency astronaut and a former International Space Station (ISS) crew member.

The first is that AR and VR technologies will appear as a type of technology exhibit (not just a display tool) in the Museum of Science and Technology, where the history, development, and exploration of the future will emerge. The interpretation of AR and VR depth will be a new contribution to the Science and Technology Museum. At the same time, based on this kind of paving, it will be smoother in the process of users using AR and VR.

Further, we can use AR and VR to reproduce scenes that are difficult to represent in a limited space of the room. As mentioned above, wearing a helmet in a small exhibition hall brings the audience into an infinite universe. This transition from physical space to virtual space saves the economic cost of producing a special exhibition hall (the cost of these buildings is often much higher than the cost of VR equipment); on the other hand, each user is assigned to a VR

Fig.2.31: Users in Puntam Museum
Source:

device. This means that each user can use this virtual space independently without being bothered by other users. Another compelling case is named "Air, Land & Sea", Air, Land & Sea, INDE's large-screen Augmented Reality experience was a perfect fit for the Putnam (Fig.2.31), a museum and science centre where people connect with history, nature and ideas by doing and experiencing. Different from the traditional AR experience, the museum hopes to break away from handheld devices such as mobile phones and use technology to integrate virtual images and videos with the live audience through a large screen to form an augmented space experience. It created in collaboration with the National Geographic Society, and the AR experience allows visitors to get up-close and personal with a diverse range of animals from Africa to the Arctic as they graze, drink, and interact with the environment around them. The museum strives to achieve the following scenes: When visitors act in a designated area, images of wild animals and the image of the visitors appear on the screen. The image of the wild animals can be responded to according to the behavior of the visitors. The virtual space background generated by the AR technology is well combined with the original space and can recognize the human body to give the correct occlusion relationship. This screen acts as a mirror, except that it reflects a variety of virtual elements in addition to reflecting the user's real state. From the general cognition of the user, the object in the "mirror" should be truly present in the current space. In fact, the exhibition hall is empty, this wonderful relationship brings an augmented experience to the user, and the experience of the original space is raised to a new field through virtual technology.

AR and VR also have an impressive form in the

Science Museum, and these virtual technologies can be used to convey scientific knowledge to users through fun games. In this case, some intangible things are presented on the device by technology in the form of augmented information. In turn, this space has evolved from the original space into an augmented space. A typical case is named "Math, Science, Recess" in New York Hall of Science. In this case, they developed five "noticing tools" to help students recognize invisible scientific and mathematical forces at work while they're at play. Using iPads, students learn about everything from proportions and fractions to physics and 3D modeling, while participating in activities they enjoy (Fig.2.32). Some research showed that the more deeply involved students were in each aspect of what they were learning, the more they retained. As they said on their website: *"We began by testing the simplest of playground activities, quickly prototyping a sensor-laden mat that could track velocity, force and motion, as kids slid down a slide. We quickly realized that students needed a bigger, more interactive role in the tracking process, so we went back to the drawing board. In the end, we used the powerful suite of sensors built into Apple iPad to make each math and science concept come alive."*[1] This powerful interactive tool and application greatly enriches the user experience and makes an ordinary space very interesting under the blessing of AR effects. Using the original space as a background, combining augmented information with the user and learning knowledge in it, this experience not only increases the user's enjoyment but also helps them better understand science. It can be said that this model will appear more in the technology museum in the future.

Fig.2.32: "Math, Science, Recess" in New York Hall of Science.
Source:https://localprojects.com/work/noticing-tools-for-ipad

1. https://localprojects.com/work/noticing-tools-for-ipad

2.3.4 Art Museums

Art Museum is an architectural space for art collection and exhibition. It also carries art and cultural communication and social activities of various art forms.

In art museums, because art is often avoided as much as possible in direct touch with the audience, vision can be said to be an essential way to convey to the audience. AR and VR technologies can visually provide an augmented mode in which users can better assist in getting more extra information while browsing the artwork. In the traditional browsing mode of the art museum, information such as the author's information and background of the artwork often appears in the form of text next to the artwork. It is difficult for the user to read the information while browsing the artwork. The splitting of this kind of information is particularly obvious when the size of the artwork is immense. The audience needs to feel the whole picture of the artwork through long distance, and the explanatory text requires the viewer to move a certain distance to read. AR technology provides a solution to view the artwork while using the mobile phone camera to display the artwork, and then display the relevant information of the artwork on the screen of the mobile phone. Come out and let the audience appreciate it more precisely. For example, in Museu de Mataró[1], visitors can use iPad as AR platform to watch artworks. When visitors use iPad focus on an artwork, the AR application can recognize the image. On the screen, visitors can see floating information on the original image (as shown in Fig.2.33). Then visitors can touch the icon and understand more information on the artwork.

With the AR application help, visitors do not have to go very close to reading boring text messages but look at the information in a smart age, which is not just text, but also images, audio and video. Even more

1. The Mataró Museum is a museum in Mataró, in El Maresme, with a central office in Can Serra, a fortified Renaissance building dating back to 1565.

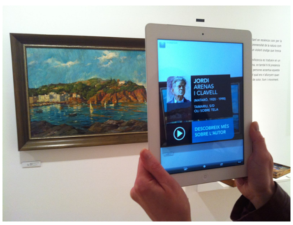

Fig.2.33: AR application in Museu de Mataró
Source:

convenient, multiple users can also use their own devices to view this information simultaneously, instead of the traditional way of browsing which visitors have to read the information text one by one. Behaviorally, the intervention of electronic devices creates a mediated indirectness between the visitor and the authentic artwork. However, this intervention does not sever the connection between the visitor and the artwork; the virtual visual technology provides additional information and ways of understanding while ensuring the artwork's authenticity. Artworks are usually not easy to understand, especially for non-professionals, often need to use auxiliary reading information to facilitate understanding. With the help of this virtual technology, users can read artworks through APP and augmented information. This also indirectly changes the user's viewing mode, which in turn affects the interior space design. Users no longer face the artwork directly, but face the equipment and face the artwork.

At the same time, the use of virtual devices in the art museum can bring a whole new experience. With the popularity of virtual technology and the enhancement of computing power, virtual art will become a new art form in the future. The category of art has always changed with the development of technology, from the birth of the camera to the art of photography, and then to the art of film. The evolution of virtual visual technology has opened up new creative possibilities for artists, and the infinite extension of the "canvas" and its high degree of integration with real space has brought a richer diversity to art. Virtual Reality film "Carne y Arena"[1], won awards in various film festivals is an affirmation of virtual technology and art. When a virtual object expresses a part of the artistry, it can be called a virtual art. With AR and VR, the artist's creative space is further enlarged. In the virtual space, the artist

1. Flesh and Sand (Carne y arena) premiered at the 2017 Cannes Film Festival as part of the official selection and was the first virtual reality project to ever be featured at the festival. It was later featured at the Prada Foundation in Milan, attracting significant international It is awarded the first Special Achievement Academy Award in over 20 years by the Academy of Motion Picture Arts and Sciences

Fig.2.34: Felice Grodin: Invasive Species
Source: https://pamm.org/ar

can ignore various factors such as gravity and material to create various kinds of artwork. In the near future, art museums will also have space to experience virtual art. These spaces may be physical or maybe in the enhanced space of construction. Virtual technology can help us achieve some creations that are difficult to achieve in reality, which is a rare soil for artists to cultivate crazy imagination. This virtual space and art can get rid of the limitations of physical laws and create some immersive, simulated, and dreamy works of art.

The following case "Invasive Species" (Fig.2.34) explains this situation very well. *Invasive Species is a virtually interactive, digital exhibition of commissioned works by Miami-based artist Felice Grodin. The series employs the technology of augmented reality and is accessible to visitors using iOS devices in PAMM's outdoor areas and in the Padma and Raj Vattikuti Learning Theater on the museum's first floor. By drawing on her training as an architect, Grodin analyzes the relationship between physical and mental territories. She explores the mutable within landscape, architecture, and our urban surroundings. Featuring four site-specific digital works, Invasive Species virtually interacts with PAMM's architecture and transforms the museum's environment as a response to Miami's ecological reality. For example, in Terrafish (2017–18), Grodin overlaps PAMM's hanging gardens on the waterfront terrace with the translucent body of the digital species she created—a work suggestive of nonnative jellyfish found in South Florida waters. In Field Report [2518] (2017–18), cryptic signs run over the entrance grounds of the museum carrying a subliminal message from the future. By drawing on the destructive impact of invasive species and creating new digital environments, Grodin highlights the*

1. https://www.pamm.org/ar

transformative and unstable state of our ecosystem, speculating about a not-so-distant future affected by climate change and overtaken by uncanny creatures[1].

In the art museum, another role of AR and VR is to understand the works of art from a new angle. Here we use a piece of art from Escher as a case to illustrate. Maurits Cornelis Escher, a versatile graphic artist, has created many impressive graphic artworks throughout his life, including some representations of "Impossible Spaces" (as seen in Fig.2.35). These graphic artworks are often firmly based on mathematical relationships among shapes, figures and space. Additionally, interlocking figures based on the use of black and white to enhance different dimensions are explored. With the help of VR technology and equipment, these potentially multi-dimensional graphic works of art can be digitally reconstructed and expressed in the form of three-dimensional spatial simulations (Fig.2.36). His artwork Relativity is a perfect regular space in the Euclidean world. Therefore it seemed to work well for a simple 'entry-level' test case to experience. The three directions characterizing the real space are here respected. The 3D model's construction has been easily carried out, also with the help of the light, generated by a light source located above the upper limit of the image. We try to rebuild it in the 3D model and represent it through VR, and we can walk in the artwork and choose a different person's perspective. Through the perspective supposed to be seen by the selected different people appearing in the painting, and the related images graphically reproduced according to their position, we can further understand the Escher's shaping of this impossible space through a unique panorama view. Instead, the viewing point's continuous change and its orientation seem to be the only possible way to experience this

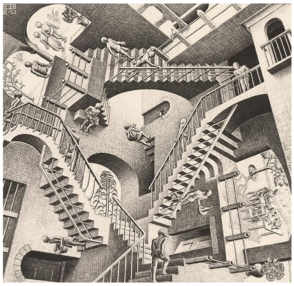

Fig.2.35: M.C. Escher, Relativity, Lithography, 1953 MoMA, New York, USA

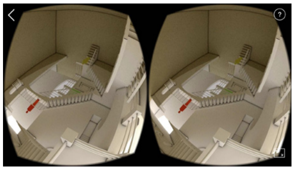

Fig.2.36: Relativity Rebuild in VR mode
Source: Made by author

space from inside, that is, without any privileged, primary, or absolute sight position. Therefore, a kind of perceptual 'relativism' emerges, since none of the visions proposed is more 'true' than the other. Neither our vision, that is, the one proposed by Escher, since it shows, again, only one among the infinite number of images available in that multi-gravity environment.

In summary, in the art museum, AR and VR have many functions, including but not limited to helping users better understand artworks, creating new forms of virtual artworks and re-deconstructing some works of art. These roles have a profound impact on the way users view and museum space. In the future, we need to consider the new adjustments brought by these changes in the museum space design.

2.3.5 Site Museums

Although for some years the term "site museum" has repeatedly appeared in museological and other literature, it has only seldom been analyzed systematically and to any degree of scholarly precision. Use of the term developed during the 1950s when the American expression "trailside museum" became in the French translation le muse' e de site. Three years later, the English re-translation "site museum" appeared in the journal Museum.' In 1982 ICOM defined the (archaeological) "site museum" as a museum Conceived and set up in order to protect natural or cultural property, movable and immovable, on its original site, that is, preserved at the place where such property has been created or discovery.

A definition with a wider subject field, is that of Küsel: *The Site-Museum preserves and interprets the remains of cultural history or natural history phenomena on a site where these have been preserved in situ or* *reconstructed. A Site-Museum also has, like any other museum, the functions of conservation, documentation, research and interpretation*[1]*.*

1. Küsel, Udo. "Open-air Museum versus Site Museum" (Presented at SAMA Conference in 1988). SAMAB 18 (5), (1989): 183–185.

Although the site museum is not as attractive as the art museum in the previous questionnaire, its unique cultural and historical characteristics are irreplaceable. At present, the site museum lacks a new form of reconstruction of its original, and the restoration of historical remains in digital form can present new forms of expression and experience under the influence of AR and VR. Many interviewees believe that VR and AR are the best partners in the site museums. This also proves that VR and AR are able to reactivate these museums.

With Augmented Reality, historians and architects can attempt to restore the original appearance of the site itself by covering the site with a new layer of virtual layers that fully represent the original state of the building through smart or head-mounted devices. The process of its construction and gradual demise. It can also be used to locate different information signs on the site to help viewers better understand its meaning. VR technology allows users to be placed in the original environment of the site in a more immersive way. Imagine that we wear the VR helmet and return to the magnificent scenery of the site which built a hundred years before through virtual technology and images, like sitting on a time machine. This experience is far more reliable than traditional text and video.

1. http://jamcreativestudios.com/

JAM[1] group created an augmented reality (AR) app to allow visitors to see structures on the landscape that have long since disappeared (as shown in Fig.2.37); among them an Iron Age hill fort, a ruined castle and an ill-fated packet steamer that had been

Fig.2.37: Glamorgan Heritage Coast AR APP
Source: https://apps.apple.com/gb/app/glamorgan-heritage-coast-ar/id1050672433

wrecked along the treacherous coastline in 1831. To accompany each of the recreations, they produced animations describing their stories in more detail. They incorporated AR triggers into postcards and beer-mats to encourage visitors to download the apps while they were within a wi-fi signal and then entice them out to explore the coastline further. These images triggered AR animations to give visitors a taste of what lay in store for them along the coast. To encourage younger visitors to engage with the myths and legends of the area JAM group also created Wreckers Run, a mobile game that explored the stories of the wreckers who terrorized the coastline during the 16th century. Players navigate their ship along the treacherous coastline, dodging sandbanks, rocks and the dastardly deeds of the wreckers along the way.

Engaging and immersive is still currently lacking in the site museums. The characteristics of virtual technology perfectly complement these shortcomings. With virtual technology, users can experience the traces of history in ruins. However, please do not think that the glory and dumping of these ancient ruins are too far apart from our time. Even famous buildings like Notre-Dame de Paris still cannot escape the terrible disaster.

Fig.2.38: Notre-Dame de Paris on fire

While undergoing renovation and restoration, the roof of Notre-Dame caught fire on the evening of 15 April 2019 (Fig.2.38). Burning for around 15 hours, the cathedral sustained serious damage, including the destruction of the flèche (the timber spire over the crossing) and most Of the lead-covered wooden roof above the stone vaulted ceiling. This is a regrettable disaster for the architecture and even the entire human civilization. Following the April fire, many proposals were made for modernizing the cathedral's design. However, on 16 July 2019, the French Parliament passed a law requiring that it be rebuilt exactly as it appeared before the fire.

We all know how much time and economic support it takes to rebuild at this level, and we are not even sure if people will be allowed to visit as before. In response to this situation, Ubisoft[1] decided to use VR to help people complete this virtual tour. Ubisoft has debuted a virtual reality tour of the World Heritage monument of Notre-Dame de Paris at the UNESCO headquarters in Paris. The preview happened during their "Journées Européennes du Patrimoine" (European Heritage Days) on September 21st and 22nd. The VR tour gave people a chance to check out the cathedral before it had burned down earlier this year. With the help of VR equipment, visitors can enjoy the immersive way of Notre Dame in more than ten special scenes which included the choir in the interior of the cathedral. The VR kit even allows users to enjoy the rooftops of Notre Dame where the user does not easily visit even if before the fire in the air by taking a virtual hot air balloon (Fig.2.39).

1. Ubisoft Entertainment SA is a French video game company headquartered in Montreuil with several development studios across the world.

This VR experience is based on Ubisoft's recreation of the Notre-Dame in the 2014 video game, Assassin's Creed Unity, which is set in Paris during the French Revolution. This demonstration at UNESCO's Heritage Days was only the beginning as Ubisoft aims to provide experiences like these accessible to more people in the future.

Fig.2.39: Child using VR in UNESCO to experience virtual notre dame

"For the last 30 years, Ubisoft has been creating immersive worlds in which it is possible for players to entertain themselves or— in the case of the Assassin's Creed series — to discover and appreciate a part of world heritage," said Ubisoft's SVP of New Business Deborah Papiernik. *"We are proud to show*

the excellent work our teams have carried out in the creation of Assassin's Creed Unity, and to allow the public to visit the cathedral thanks to this virtual reality experience."

Nowadays, many sites and heritages are building and perfecting virtual VR models. In the future, we will see more heritage sites appear in VR glasses, and bring them the shock and glory of history through these virtual models. Although the discussion about the authenticity of the site, that is, the fact that we visit the site through virtual technology at home is still very different from the site visit, as an aid oraugmented means, the prospect of virtual technology in the site museum is still positive.

2.4 Conclusion

As an emerging virtual vision technology, AR and VR have produced significant progress and development since their birth in the 1950s. In several decades, it has gradually entered the stage of popularization and application from the concept and experiment stage. Under the influence of the market economy, new technologies and equipment have become popular among users. This influence also affects museums and exhibition spaces. Although VR and AR history is short-lived, its impact on museums and exhibition space will be profound. The positive attitude of VR and AR's future development is one of the conditions that promote the continuous evolution of virtual technology in real space. In several typical museums (science and technology museums, art museums, site museums), virtual technology creates new spaces of interaction and immersion in different attributes that activate the museum and give users a better experience.

1. Present additionally augmented information:
Additional enhancements (text, images, video and even 3D models) can be displayed on the exhibits with different types of AR and VR technology. This augmented information is more attractive to the user and more natural to receive. In addition to exhibition and collection functions which are the most critical roles for museums, it also carries multiple attributes and responsibilities such as education and cultural communication. The interactive, gameful, and participatory information and elements brought by this new technology are the most demanded of museum space. From a spatial perspective, this change will have an impact on the size of the interaction between the user and the exhibit. Digital information appears in the physical space in a more realistic way, and together with the physical space constitutes an augmented space or virtual space. This new space not only has the spatial relationship and logic of traditional architecture but also has the new characteristics endowed by the digital age. Elements and information (real and virtual) in museums and exhibitions will be conveyed to visitors in a new form.

2. Build unbuildable space:
The primary objective of building unbuildable space is to visually create a spatial experience that cannot currently be built in physcial world. The "unbuildable" here actually consists of two aspects. First, it cannot be built due to economic costs or building protection. Virtual technology can be built in an immersive and low-cost way, and user feedback can be obtained from it. Based on these feedbacks, it can counteract the digital construction of the virtual space. This dynamic, updatable digital building will have a positive impact on the architect. Through the user's behavior and evaluation in the virtual space, better feedback can be

given to the architecture design; on the other hand, it is completely The space that cannot be built in the real world, the shock of this kind of creativity can bring a new form of art and space through virtual technology. This means that architects will have more conditions and capabilities to shape new building spaces. In the past, this kind of space can only appear in science fiction movies and video games, and now under the guidance and creation of architects, this virtual space which more easily perceived by visitors will be worth more expectations.

3. Create new experiences:
With virtual technology, the interaction model between the audience and the exhibits has undergone fundamental changes. Without the physical interaction device, the composition of the space is significantly saved. We can even simulate a space that is entirely inconsistent with its size in a small environment. In the face of this new technology, architects and artists will have more possibilities to help users gain a new experience in the museum. The spatial changes brought about by the changes in experience have also prompted the museum space to transform into an experience-driven space model gradually. In this model, the user experience will be the core consideration for space design. This upgrade of the experience does not mean that the museum's primary function will transform into pan-entertainment. Collection and display, as museums' primary functions and their educational, communicative and entertaining functions arising from their cultural attributes, will be upgraded and the introduction of new technologies will create new user experiences.

2.5 Short List of Bibliography

1. Arth, Clemens, et al. "The history of mobile augmented reality." *arXiv preprint arXiv:*1505.01319 (2015).
2. Bleeding Cool. "Ubisoft Has Recreated Notre-Dame De Paris In A VR Tour". Accessed May 10, 2020. https://bleedingcool.com/games/ubisoft-has-recreated-notre-dame-de-paris-in-a-vr-tour/
3. Heilig, Morton L. *"Sensorama simulator."* U.S. Patent No. 3,050,870. 28 Aug. 1962.
4. Kato, Hirokazu. "Inside ARToolKit." *1st IEEE International Workshop on Augmented Reality Toolkit.* 2007.
5. Küsel, Udo. "Open-air Museum versus Site Museum" *SAMAB 18 (5).* 1989.
6. Mazuryk, Tomasz, and Michael Gervautz. *"Virtual reality-history, applications, technology and future."* (1996).
7. McLellan, Hilary. "Virtual realities." *Handbook of research for educational communications and technology* (1996): 457-487.
8. Schueffel, Patrick. *The concise Fintech compendium.* Switzerland: Fribourg. 2017.
9. Sutherland, Ivan E. "The ultimate display." *Multimedia: From Wagner to virtual reality 1* (1965).

CHAPTER 3

USER EXPERIENCE AND ITS ELEMENTS IN AR,VR AND MUSEUM SPACE

3.1 Introduction

User experience is a person's attitudes, feelings and feedbacks about using a product, system or service. User experience is essentially a subjective feeling from the user; this feeling comes from the user's interaction and communication with the objects he uses including a personal perspective of product such as efficiency, convenience and aesthetics, etc. With the development of computer technology and the Internet, the form of technological innovation is undergoing a shift, and user-centricity and people-centeredness are gaining more and more attention. User experience emphasizes the users' feelings under human-computer interaction. Because of this, user experience as an essential indicator has been applied to the field of Internet technology and digital widely such as websites, software and mobile applications. With the progress of the times, the importance of user experience becomes more evident in the AR and VR, which are the leaders in virtual vision technology. Furthermore, when we extend this design context to the field of architecture, we can find that architectural space design, especially interior space design, is similar to the concerns of digital media in the field of user experience.

For example, in architecture design of museum exhibition hall, we need to consider how many people are to be served in the exhibition hall, how to interact with people and exhibits, and what kind of action route people have in the exhibition hall etc. This seems to make the design framework of architecture and the design framework of digital products stable to a certain extent in the user experience perspective. In the design phase of both fields, there are also some similar questions to resolve: What is the user group who uses the project or product? How large of the user group does the project or product serve? Can the investment in design bring the expected reasonable return? And how to collect and process user feedback, etc.

Architecture and digital products are to help a group of users solve specific problems, and provide as much artistic and aesthetic needs as possible on the basis of solving the issues. The practical characteristics and aesthetic values of architecture also share many similarities with digital products. From a particular perspective, architectural design can be understood as a mega product design based on physics and space (including real and virtual space). Space is both the language of architectural design and a medium which allows an intangible interaction between users and structures. And a building, the result of architectural design, can be seen as a tangible digital product. In fact, in the context of the digital age and the Internet of things, there is a crossover between the fields of architecture and digital product design, especially in terms of user experience. This kind of interdisciplinary research on user experience between architecture under the influence of virtual vision technologies and digital products is of far-reaching significance. In this chapter, it will discuss a framework from user experience which is a relatively new design trend in the digital era, and conceive how this framework plays a role in the current exhibition building and influence the design method of future museums.

3.2 User Experience and Its Parameters in Augmented Exhibition

3.2.1 User Experience in Virtual Vision Technology

3.2.1.1 Introduction

At the beginning of the digital product, almost no so-called user experience was considered, and the stable operation of its functions was the main task of digital products at that time. For example, the first VR prototype "Sword of Damocles" (made by Ivan Sutherland in 1968) did not take into account how to make the user more comfortable and easier to use and not to mention that there is almost no aesthetic element at the time of design. This allows the prototype of a digital product to be hung on the ceiling of a laboratory-like a large steel monster in the mechanical age. In this case, it seems impractical to propose a so-called user experience. It is already a breakthrough to successfully run the entire machine (Fig.3.1).

Fig.3.1: "The Sword of Damocles" ,the first VR prototype of immersive world
Source: Sutherland, Ivan E. "A head-mounted three dimensional display." Proceedings of the December 9-11, 1968, fall joint computer conference, part I. 1968.

After gradually meeting the basic needs of functionality, the user experience is slowly being valued by the design community. When designing products from the experimental phase to the commercial phase, this change in demand is even more pronounced: designs that focus more on user experience tend to achieve more tremendous success, both from a design and market perspective. With the continuous development of digital products, the user experience has received an unprecedented level of attention. User experience design aims to understand the user's psychology, usage habits, purpose and aesthetic tendency, and build a digital product that addresses the user's objective needs.

3.2.1.2 User Experience in Digital Interactive

As mentioned in the previous article, user experience design, in a sense, is to let users get a better experience in the process of using products or services through design methods, whether it is a physical product or a digital product. An essential difference between digital products and other design products is: The object that completes the interaction or the feedback obtained is virtual. Participator can feel a designed user experience everywhere. The interact method with digital products, the buttons' location, and their shapes are all examples of the elements that build the user experience. When people use the product, all their interactions with the product become their experience. Every day, people face countless digital product interactions, sending and receiving information and mails via mobile phones, buying tickets on the subway with touch screens, working on the Internet, shopping, etc. In the process of dealing with various digital media, all of us could have a similar experience: we will love the easy-to-use and stunning user experience design; we are distressed and angry about the bad, lame user experience design.

As *Jared Spool*[1] said*:"Good design, when it's done well, becomes invisible. It's only when it's done poorly that we notice it."* Still, a good user experience has the following features:

1. Jared Spool is an American writer, researcher, speaker, educator, and an expert on the subjects of usability, software, design, and research.

1. Provide enough of the right information:
A good user experience design will give users the most useful help at the information level. For example, if a digital device has some errors, the information it provides should not be only that the device has errors, but precisely where the error occurred, the possible cause of the error, and the solution.

2. Avoid visual clutter
By focusing on the most valuable content for users, is one of the most effective measures for enhancing the experience, especially for digital products that require text reading. This approach emphasizes readability because a user's attention is limited. The conflicting visual hierarchy may be one of the most common problems users face when then use digital interaction. When too much useless information appears, the user's attention will be drawn away, and the user may not find what he needs.

3. Alleviate the user's uncertainty
When users use digital products since there is usually no other person to participate and guide, all inputs and outputs should be as clear as possible and reduce uncertainty. When users are hesitant or uncertain about the triggering, filling and other feedback of an item, the bad emotions brought by this experience will have a negative impact on the entire product. Therefore, alleviating user uncertainty in digital products is extremely important and critical.

Virtual vision technology (mainly AR and VR) faces some new challenges in user experience. Since the use of platforms, communication media, and interaction methods have undergone substantial changes, how to define the experience brought about by some new interaction modes and how to improve it has become a new issue in user experience. The primary challenge of new technologies at the user experience level is reliability: People are often skeptical about new technologies that may change their lifestyles in the future. If the new technology brings bad experience to the user in the initial phase, the negative experience impact will be magnified and isolate a large number of users from the new technology. As *Daniel Terdiman*[1] pointed out*:" [VR companies] are keenly aware that bad VR experiences on any platform or any device can turn people off to the entire technology forever."*

1. Daniel terdiman is a san francisco-based technology journalist with nearly 20 years of experience. A veteran of cnet and venturebeat, daniel has also written for wired, the New York times, Time, and many other publications.

In the framework of virtual vision technology, the following principles of user experience should be taken into consideration:

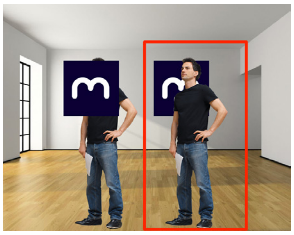

Fig.3.2: front-to-back occlusion relationship between real objects and virtual objects.
Source: https://medium.com/modeso/augmented-reality-using-tango-b30b3b6806a

1. Believable:
This can be said to be a new feature brought by virtual vision technology. Due to the characteristics of real-time rendering and the combination with the real world, users can be convinced that virtual objects really exist in the real world. For example, in the use of some AR applications, the system cannot correctly identify the front-to-back occlusion relationship between real objects and virtual objects (as shown in Fig.3.2). The virtual object (Logo) is "placed" on the building space (Wall) by the AR system, but due to the appearance of the front object, the effect of the left half of the picture will appear on the device, that is, the wrong logical position. According to the current object recognition technology and computing power, AR technology is difficult to correctly identify the front occluder and

make correct feedback on the virtual object. Therefore, at the level of user experience, such operations that reduce trust should be avoided as much as possible to ensure the continued use of users.

2. Interactive:
Virtual vision technologies must be interactive to work properly, so when a user makes a corresponding action, the digital objects must replicate these actions. As the core link of digital product user experience, interactivity has significant value. Excellent interaction and corresponding feedback can make the application closer to real life. In the entire virtual experience process, the ability to comprehensively use various interaction modes can raise the user experience to a new level. In the design process of AR and VR, injecting virtual elements into interactivity and operability as much as possible means that users will be more willing to explore in the augmented environment constructed by the designers or architects, thereby enhancing the user's sense of pleasure in using the product.

3. Explorable:
A good virtual vision project must not only be completed by "seeing". Different from the traditional two-dimensional expression modes such as videos and images, users need exploratory projects. AR and VR can better create virtual environments and help users explore in virtual and real environments. An excellent virtual vision project will give the initiative to the user and let the user discover some more in-depth content during the exploration. With interaction elements and game elements, the sense of exploration will become one of the critical evaluation criteria for AR and VR in the future.

The user experience design of the virtual experience should be as convincing as possible. This means putting the user in control and having complete control over the experience. To make users forget that they are in a simulated reality, they must be interactive. To solve this problem, much virtual vision means to provide a fully immersive experience.

3.2.1.3 Key Elements

User experience design is a relatively recent subject. Despite this, experts in this area have given various academic studies and frameworks to user experience and extracted vital parameters. Relying on these frameworks and parameters, it can help organize our thinking around understanding users and designing extraordinary experiences for them. The widely recognized framework in the digital design field, "Elements of User Experience", proposed by Jesse James Garrett[1] can be seen as an excellent example to discuss and study. The diagram Fig.3.3 shows a holistic view of user experience and describe different abstraction levels which occur during the users'activities. According to the design process and the user's attitude towards using the product, the framework is gradually divided into five levels from the most basic user needs to the final visual effect. They are:

1. Jesse James Garrett is a User Experience Designer based in San Francisco, California and co-founder of Adaptive Path strategy and design consulting firm. His diagram titled The Elements of User Experience launched his popularity in the web design community in early 2000

Layer 1. Site Objectives & User Needs:

As the lowest level of requirements, user requirements are the first content to be considered in user experience design; the product needs to meet the most basic requirements of users in terms of functionality, although there may be some conflicts with the needs of the designer (mainly referring to the interests and content requirements). So at this level, designers need to consider the balance between clients and users.

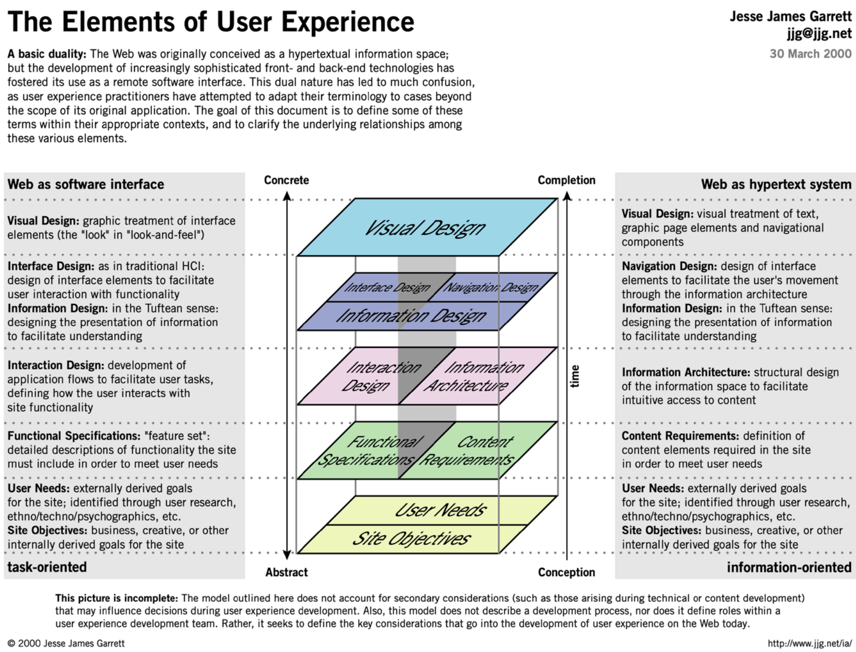

Fig.3.3: The elements of user experience
Source: Deaton, Mary. "The elements of user experience: user-centered design for the web." interactions 10.5 (2003): 49-51.

Layer 2. Content Requirements & Functional Specifications:
Content requirements are easy to understand, but the amount and type of content will need to be carefully decided and considered how to layout (such as progressive or side-by-side). Functional Specifications refers to how the content will be delivered. It mainly refers to how to deal with the limitations and differences caused by the size and performance through different platforms and devices.

Layer 3. Information Architecture & Interaction Design:
This part mainly refers to how to structure various information and elements reasonably and communicate them to users through interactive means. The core issues that need to be addressed here are: How is all

the information organized, and how can you interact with it all?

Layer 4. Interface, Navigation & Information Design:
Aesthetics begins in this step of the intervention design; basic information and interface can be conveyed to users from a functional perspective. Information design is to present information that is easy for users to understand in a more efficient way. Based on these elements, digital products with basic functions can be completed.

Layer 5. Visual Design
As the final layer of the design framework, it is also the final visual presentation of the results to the users. Aesthetics is extremely important at this layer and relates to the user's first impression of the overall user experience design. Exquisite visual design will attract users from the beginning and almost determine the user's evaluation of the entire application or product although the visual design is the last thing in the overall framework that needs to be considered by the designer.

In general, the content of each level depends on the content of its lower levels. In other words, when the designer changes the content of a certain level, the content of its upper level will change accordingly. This change is also mutual. For example, if you want to adjust the content of the "information architecture" part, you can achieve it by modifying the layer of "content requirements". There is also another possibility that the design of the upper layer is not reasonable so that the parts of the next layer cannot be fully presented. Ultimately, in order to correctly display the user experience, we need to do our best at every level.

3.2.1.4 Conclusion

User experience plays a pivotal role in the design of today's digital products. Despite the rapid pace of technological advancement, its fundamental principles and framework are still valid and can guide designers to make better designs. Virtual vision technology helps users to experience the sufficient support of trust and immersion from the technical level and confirms the feasibility of the service framework of user experience design proposed by *Jesse James Garrett* to this day.

Simultaneously, as a tool for creating space (virtual or augmented), such elements and frameworks can provide great help and reference in the design of architecture and space environment.

3.2.2 User Experince in Space

3.2.2.1 Introduction

The user experience in the architectural space refers to the feelings, behaviors and attitudes of the users when they "use" the space composed by geometrical volumes. Compared with digital products with only a few decades of history, the development of architecture has lasted for thousands of years. Among them, the evaluation system and design theory of architecture have continuously developed and changed, showing a posture of blossoming flowers. As the art of space, architecture should focus on the creation and change of space. The users of the space and their feelings in the space also need to be valued. The rise of UCD (User Centered Design) is evidence of its importance.

The exhibition space is a special existence in the architectural space. Due to its precise positioning of the user group, the high demand of the user and the content of the exhibition, and the variability of the interior space, the user experience design plays an important role in the overall design process.

3.2.2.2 User Experience in Museum Space

The user experience of architectural space can be roughly divided into two categories: exterior experience and interior experience. From the perspective of exterior experience, such as the exhibit designed by *Grafton Architects, "Architecture as New Geography"*[1], to get architecture out of the making and thinking of isolated objects and to show it as an inexorable transformation of nature. Users walk around the architectural structure through the vision experience and its external shape. The huge shape in the light and shadow changes from the visual experience to the users is the main feature of the exterior architectural space experience. The user experience of the interior part in architecture can be described as an American architect Dominic Mercadante said *"The second aspect is more experiential and is best understood as the building as an assemblage of spaces. The emphasis is on our direct experience of the building through time. As we move from space to space our perception of the one we are entering is colored by our experience of the one that we are leaving. All aspects giving form and definition to a space are involved here: there is the shape and proportion of the space itself, the relative solidity or transparency of its walls, floor, and ceiling as well as the colors and materials used to define and articulate these surfaces."*[2]

1. The exhibit 'Architecture as new Geography' is showed in the 13th Venice Architecture Biennale and explores the work of the Brazilian architect Paulo Mendes da Rocha in the context of Grafton's new project for a university in Lima, Peru

2. https://mainehomedesign.com/design-theory/1140-the-spatial-experience/#close

Unlike other public buildings, the core value of a museum or exhibition space base on the expression of its content, and most of the exhibition content will be accepted by users' vision as the main communication medium. From the perspective of spatial experience, its controllability is further reduced. Then taking visual communication as the essence and considering the user experience from the elements of architectural performance, the main architectural space elements that influence the user experience in the museum's interior space can be summarized:

1. Volume:
The volume here is not only a closed entity but only the basic volume of the interior architectural space, that is, the internal hollow space system surrounded by walls, floors and ceilings. The shape and size of this space It directly determines the emotions and attitudes of users. For example, narrow spaces allow users to be guided. The low space makes the user feel oppressed; the small church-like space brings the mystery to the user, etc. Not only changes in size and proportion, but the shape is also an important factor affecting users.

Mass determines the basic form of space. From the perspective of traditional architecture and structure, this basic form cannot be easily changed when it was built. Once the building volume is completed. it can be quite laborious to make changes and modifications to it. For public buildings such as museum exhibition spaces, the renovation and expansion of the space is always a major project and can affect the flow of visitors. If museums use the virtual experience technology to change the user's vision in volume level, the user's emotional changes will be quickly mobilized. The reasonable use of this change will impress users in the process of experiencing the exhibition. Although the current virtual visual presentation of building volumes is still very different from the experience in a real environment, the rapid update, convenience and unique experience of virtual content provides a new dimension of volume. The following illustration (Fig.3.4) contains a possibility to change the volume, using AR technology to create a "portal" in real-world space. *"A* *virtual portal can be used in AR applications, which can lead the users to different worlds. The content of these worlds is up to the developer of the application, but in this specific case, it could be either a museum or a monument. The virtual portal could be placed on a flat surface in the real world by the users. When they look inside the portal, they will be able to see a part of the virtual world that is located behind it. Moreover, if they walk through the portal , they will be transferred to the virtual world and will be able to explore it by moving in the real world, while holding their device. Finally, by walking through the portal again, by facing in the opposite direction, they will be able to leave the virtual world and return to the real world."*[1]

1. https://www.vi-mm.eu/project/case-study-for-augmented-reality-ar-application-of-portals-for-the-preservation-of-cultural-heritage/


Fig.3.4: the portal in real world and virtual world, Geronikolakis Efstratios, Papagiannakis George, Source: Case Study For Augmented Reality (AR), Application Of Portals For The Preservation Of Cultural Heritage

2. Illumination

Illumination is very complicated in the design of the museum. Such as Tado Ando said: *"In my all works, light is an important controlling factor."* Broadly speaking, illumination can be roughly divided into two parts: natural illumination and artificial illumination. Although the development of technology allows artificial illumination to closely simulate skylight, the feelings brought by nature and the changes in light and shadow at different times are still not to be ignored. No matter what illumination mode is adopted, the exhibits should be served more under the primary conditions of lighting. Different types of exhibits have different needs for illumination. For example, some sculptures require skylight; some artworks require a dim environment, and even some exhibits require constant lighting.

The application of user experience in the lighting environment is mainly reflected in its changes. When a user walks from one exhibition hall to another, the difference in the lighting system will quickly remove the user from the immersion of the previous hall. This change in light will make the museum's content more prosperous and more attractive.

With the help of virtual technology, you can also create virtual lights. This kind of creation looks easier. Instead of relying on the limitations of the real physical environment, you can use computer rendering technology to create light sources that designers need in a virtual environment. This light-changing experience, coupled with the unique sense of exploration and immersion of digital applications, can bring a new user experience. Even with the VR system in a completely virtual environment, the designer can fully use the lighting design to the full extent, so that

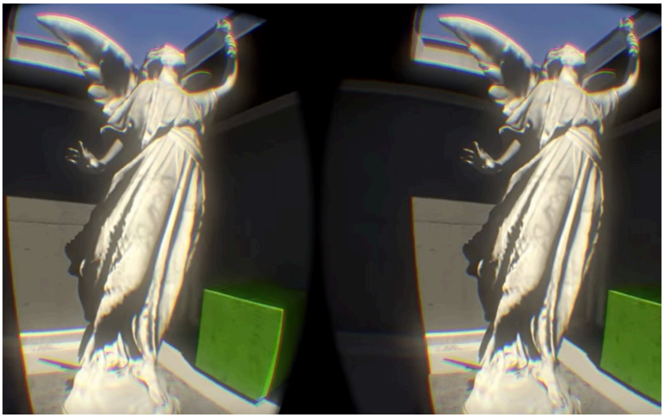

Fig.3.5: Application of ray tracing technology in VR environment

he can guide the user through the viewing experience with light. A simple case shown in the figure below (Fig.3.5) is to use VR to virtualize a sculpture exhibition. With the help of the increasingly advanced rendering technology of computer graphics, people can quickly simulate the lighting at real-time. The calculation speed and realism have reached an acceptable level. With this technology, users can experience the feeling of different lighting in other environments. In addition, designers can add a variety of possibilities to the exhibition design and present a more interesting environment and exhibition methods to users.

3. Object
Objects may be considered the core of the exhibition, where objects refer to the exhibits, furniture, etc. in the entire architectural environment. In the exhibition space, objects mostly refer to exhibits, while a small amount of furniture (such as rest seats) is also included. Since the exhibits are the core content of the exhibition space, the objects also occupy an absolutely dominant position in the entire process of user viewing.

The museum has initially been an institution for collecting and preserving objects, as well as for opening and viewing to the public. Visitors enter the museum to pay attention and interest in primitive objects. Over time, the museum's attention has also gradually shifted from the exhibit itself to the visitors. The significance of museums also ranges from the preservation of exhibits to more valuable participation in visits, such as the introduction of more educational, social, and communicative features. This kind of change museum is not only concerned with the collection and management of objects but also creates a connection and bond between visitors and objects. This connection and interaction has gradually increased with the rise of digital media in museums and turned museum user experience into a phenomenon

Different objects obviously make a difference to the user experience. Although many current exhibitions are still static, users passively accept the exhibits. The revolution in digital technology opens up more possibilities for objects in museums. In the future, interactive exhibits will become the primary means of exhibition. With augmented technology, the design of interactive exhibits will also be more diverse and more productive. For example, under the action of AR, dinosaur fossils can be restored to lifelike ancient giants; static art paintings can be turned into exciting animations; various floating information can be displayed on the statue, and so on. The user is no longer a passive receiver, but a participant in the viewing process. The changing role of objects has brought new vitality to the museum, and the interactive properties of objects have increased user participation. Increasing user participation will bring more activity, and the understanding of exhibits will also evolve from traditional text and graphic introductions to a three-dimensional, diverse, and interactive understanding.

4. Material

Materiality in architecture is not limited to theoretical positions on the perceived materiality of images, texts, or other objects of representation. It may refer to the applicability of specific projects, where one would need to consider the full range of materials used. It has also been described as the circumstance that architecture is realized using building materials as well as how a material expresses its properties and idiosyncrasies, allowing their characteristics or appeal to emerging.[1] This is also demonstrated in the way

1.Janson Alban and Tigges Florian, Fundamental Concepts of Architecture: The Vocabulary of Spatial Situations. (Basel: Birkhauser, 2014), 189.

2.Crysler C. Greig, Stephen Cairns, and Hilde Heynen, The SAGE Handbook Of Of Architectural Theory. (London: SAGE, 2012). 96

material - in the current understanding of materiality - came to be considered as an active ingredient in the processes of making architecture as opposed to being confined within the context of the social and economic context for architecture.[2]

The use of materials in architectural space is often very selective. Good architects can use building materials to convey their design concepts and ideas, as well as in exhibition spaces. At the same time, the choice of materials is also related to the functionality of the exhibition to a certain extent, including the protection and safety maintenance of exhibits. Putting aside the functional perspective, from an experiential perspective, the changes that architectural materials bring to the exhibition space are meaningful, including the properties of the material itself, soft, hard, rough, and smooth; and materials The displayed colors and transparency, etc.

Different materials in the museum space will bring different changes in mood and experience to visitors. For example, the stone material will bring a serious and solemn mood, while the wood will bring a warm mood. Tactile and auditory perception when visitors come in contact with materials will bring different user experiences. Even if it is the same material, if the surface processing technology (engraving, corrosion, oxidation, spray baking, etc.) is different from the decoration color, it will show different psychological value orientation.

Fig.3.6: INDE, "FLORIDA MUSEUM OF NATURAL HISTORY, GAINESVILLE, FL" October 13, 2017,
Source: https://www.indestry.com/blog/2018/8/21/augmented-reality-museum-examples

A compelling case is shown in the left (Fig.3.6). Under the blessing of augmented reality technology, the original concrete floor material has been turned into a wild field. The changes in materials lead to changes in spatial perception. In this augmented environment, the user's interest is stimulated, and the overall space interaction is reflected.

5. Multisensory Experience

The visual experience is the only way for visitors to interact with exhibits in most museums. Some museums even use design methods to avoid optical interference from other sense organs in order to strengthen users' visual perception. In recent years, more and more museums have begun to pay attention to the multisensory coordinated experience. Although some artworks are for the purpose of protection and prohibit users from touching, museums are also trying to use various other senses to help users improve their experience in the exhibition. The application of multisensory experience in virtual technology still mainly depends on hearing. About the sense of touch and smell often need the help of other auxiliary equipment and space design. The exquisite multisensory experience in the design of the museum can effectively help users participate more in the process of visiting the entire museum.In today's museums, interaction has become an important issue. The interactive elements of the museum (visitor and exhibit, visitor and space) help promote surprise, curiosity, aesthetics, and even chance encounters (Lehn, 2001). Many museums and galleries have installed interactive installations and provided such experimental venues to examine how these works promote and encourage visitor participation and interaction.

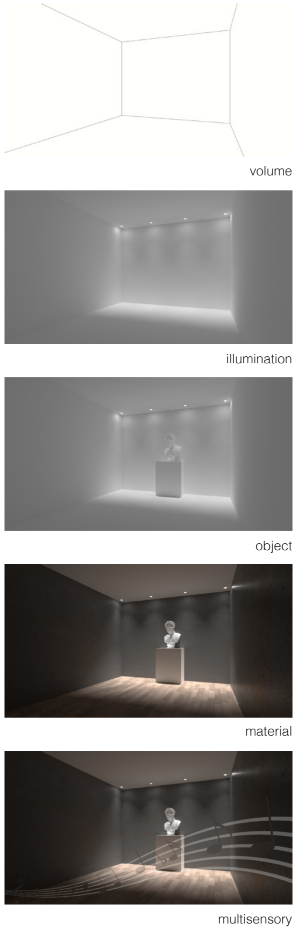

Fig.3.7: Visual elements in museum interior design
Source: Made by author

The diagram on the right (Fig.3.7) shows the gradual evolution of the five elements described above in a visually-led museum space. The five elements gradually cooperate with each other to form the final visual form of the museum space. This final visual performance result will also be directly received by visitors and become an essential part of their museum experience. The above five points can be used as architectural elements of user experience in museum space exhibitions. The use of virtualization and enhancement technologies can effectively improve the user experience from the above aspects.

3.2.2.3 Key Elements

Nowadays, museum design needs to consider how to increase user engagement and provide visitors with a vibrant place with productive learning and social elements. The rapid development of digital media and technology has reshaped the way humans express and communicate. Facing this change, the museum space must respond to this innovation. User Experience design is relevant to the digital future of museums as a potential emerging field, which could extend the focus of museum design from "spatial and exhibit design" to a broader "user experience design".

In museum space, user experience design can be discussed from the following five different dimensions, and combine these elements to complete a museum design with excellent user experience.

1. Visitors Personas:

The first thing a museum or exhibition space needs to determine is: who its target audience is or what kind of group it is. Personas are a composite profile of a person that's based on real people who visit the museum. *Personas are detailed descriptions of imaginary people constructed out of well-understood, highly specified data about real people. Personas are not actual people but are synthesized directly from observations of real people*[1]*.* As a design tool, personas provide a powerful way to communicate behaviors, goals, wants and needs. The core value

1.Adlin, T. and Pruitt, J. The Essential Persona Lifecycle: Your Guide to Building and Using Personas. Morgan Kaufmann Publishers, Abridged e., 2010.

of the user experience lies in the user's perspective, motivations, be-haviors, attitudes and feelings. In view of this, prioritizing the role of the visitor has become the primary consideration for museum experience design. After clarifying the objects to be attracted and educated by the museum or exhibition, you can add a viewing plan that is more suitable for the user group in the design.

Different museum user groups have different needs. For example, in science and technology museums, the proportion of children may be much higher than other user groups. Therefore, in the design and organization of the space, its primary users, namely young people, should be taken as the primary consideration and introduced. Design content for this group, such as safer architectural materials, more interesting games and interactive installations, and more ergonomic space and furniture design for children people, etc.

Clear visitors personas, discovering and finding the needs and targets of the user attributes, can more accurately help architects and designers improve their user experience design in the entire viewing process. At the same time, visitors use this design feedback to get the affirmation and value of self-worth.

2. Time:
Reasonable time control is essential in the museum viewing experience. On the one hand, the linear timeline and the exhibition method determine the user's viewing route; more importantly, the reasonable control of the visit time of each part of the exhibition area can effectively avoid "museum fatigue" phenomenon.

"Museum fatigue" refers to mental or physical fatigue when visiting museums or similar institutions. This kind of phenomena about museum fatigue was first described by Benjamin Ives Gilman in 1916. He mainly focused on the efforts of museum fatigue on how the viewing displays are placed[1]. He pointed out that the reason for museum fatigue is due to the exhibition method and the arrangement of exhibits. With the deepening of the research on this topic, researchers observed that the visitors in the museum found their high interest in exhibits can only last for a short time (30 mins), After that, their attention and interest began to decline significantly. This led to the phenomenon of "museum fatigue". In some studies, visitors' attitudes towards the museum change from enthusiasm to apathetic only takes 20 minutes (Beverly Serrell, 1997).

1. Gilman, Benjamin Ives (1916). "Museum Fatigue". The Scientific Monthly. 2 (1): 62–74.

Because of this, time control in the exhibition process must be considered in the design of the museum space. Although more interaction may relieve some of the "museum fatigue", it is still not suitable for more than half an hour in the exhibition process in a single exhibition hall during viewing. Adding some relief points in the middle of linear browsing is a practical design method. When the user's fatigue increases, appropriately change the exhibition mode (such as changing from standing to the exhibition to sitting down to enjoy the video) or from static viewing to interaction (Interaction-style and game-like experience modes) or the introduction of buffer zones (resting areas, coffee areas, etc.) can keep the user's interest in exhibitions from falling sharply with physical or mental fatigue. Museums may always want to show more elements and collections to the audience, and the time extension caused by such excessive elements will seriously affect the contents which users absorb from the exhibits in the later stages of the exhibition. Therefore, the reasonable arrangement of time control between the museum's exhibition halls is particularly crucial in terms of the visitor experience.

3. Interactivity:
The early form of the museum was static, and visitors receiving information in it were also passive. The relationship between visitors and exhibits was only a visual signal reception. But don't ignore community integration, education with fun and public participation can be considered an essential theme of the museum, and the interactive model can help museums achieve this target. The 21st century is an era of development and growth of interactive technology, and interactive methods and interactive elements have become diversified and mature. The emergence of interactive technologies such as speech and semantic recognition, dynamic capture, eye tracking, gesture recognition, and multi-touch has brought about tremendous changes in interactivity, which provides further technical support for an immersive experience. In the face of this change, museums have also begun to experiment with digital technology. With the development of the information age, the user's receiving mode of information has also changed from "watch" to "interactive". Users need to face various applications, websites and obtain content that interests them through operations. This change in user habits also changed the museum's exhibition model. The interaction of mechanical devices is gradually transformed into the interaction of digital media.

As *Saroj Ghose* said: *"Man [sic] has seen the agricultural revolution, the Renaissance, the Industrial Revolution and is now on the threshold of an information revolution which is likely to shape his mind in the next century. Massive assimilation of information, systematic storage, quick retrieval and unobtrusive dissemination of knowledge may lead man to a new*

1.Saroj Ghose, "People and Museums 2," in Museums 2000: Politics, People, Professionals and Profit, ed. Patrick Boylan, 1st ed. (London: Routledge/ Museums Association, 1992), 84

understanding of life and values that may mark the beginning of a new era in human civilization in AD 2000"[1]

This change in user habits also changed the museum's exhibition model. The interaction of mechanical devices is gradually transformed into the interaction of digital media.Although interactivity is so important in modern museums, it is not advisable to blindly stack interactive elements and installations. It is also because of the explosive development of content in the information age that users can access a variety of interaction modes, especially the interaction of digital products. That means if museums cannot make some innovative interaction methods and attractive experience, visitors will be bored or even bored by this "old" mode of interaction.

4. Immersion:
The immersive experience can be described as *"mentally absorbing and a process, a change, a passage from one mental state to another."* (Grau, 2003). Immersion can also be understood as an illusion. This illusion includes the illusion of position (the experiencer's feeling is different from where he is) and the illusion of plausibility (the experiencer sees different from the real environment).

This experience means that the visitor is completely transferred from one familiar environment to another, and the visitor is isolated from the real environment by the space and various senses, and then enters a new environment. The traditional museum exhibition experience tends to be elitist, with exhibits having a worship value that is magnified by the museum space. This experience leaves an invisible barrier between visitors and exhibits. The immersive experience seeks to break this barrier by allowing visitors to enter the "new" world built by the architects and designers through the "illusion" of being in the physical museum space.

For example, in the figure on the left (Fig.3.8), the wild animals in the picture above is placed in a glass box. The user will obviously be placed in a visited space, and the state of immersion is not achieved. The following picture places the exhibits in an imitation interior space, so that the user is out of the traditional museum concept and enters a new immersive space experience.

Fig.3.8: Traditional experience and immersive experience.
Up: Natural History Museum of London
Down: Museum of Science Boston

VR technology is another tool that provides virtual immersion. VR technology can completely create a virtual space and experience, placing the experiencer into a virtual immersive space. VR can also get rid of the limitations of physical conditions and create a variety of interesting and fantasy experiences.

5. Significance:
The foundation function of the museum is to collect and display. The traditional museum is to collect, protect and publicly display to visitors with cultural, historical and religious heritage. Only facing the elite group seems to be a consensus of the early traditional museums, and this situation is gradually being broken and dispelled. Facing a wider user group and enhancing the attraction of the museum itself have become new themes. This change means the transformation of the museum's own purpose, which is to add more new social meaning to the museum's functions. This mainly includes three points: education, entertainment and communication.

Education is one of the critical goals of the museum.

The museum's own collections and cultural relics are the best materials for cultural education. This became the foundation of the museum's educational value. In particular, museums have a unique advantage in history education. Museums can be designed to allow more people to participate in the educational environment with interest. This has a very positive effect on the culture and history education of the public, especially young people. Today, many museums have reached cooperation with the schools and universities, and many courses' location transferred to the museum space instead of the classroom. In the museum space, students will have a completely different experience from the classroom. Students who are studying in a museum will gain a deeper understanding of science, technology, historical value, aesthetic consciousness and so on. What more worth mentioning is exploring museums enables students to respect and understand multiple cultures, actively participate in the process of acquiring knowledge and expressing thoughts. Effective use of museums can lead to multi-faceted learning, develop critical thinking skills and acquire lifelong learning skills. As it is mentioned in *Excellence and Equity*[1]*:"...the public dimensions of museums leads them to perform the public service of education—a term that in its broadest sense includes exploration, study, observation, critical thinking, contemplation and dialogue".* In the museum space, students will have a completely different experience from the classroom. This sense of presence and close contact with exhibits have a natural appeal to students, especially teenagers. Although some exhibits can be explained in the classroom through physical display or multimedia mode, the feeling and interaction of the space have a unique charm in the museum. It can be clearly seen that the educational significance of the museum will gradually become one of the core roles of the museum.

1.Excellence and Equity. American Association of Museums. 1992. ISBN 978-0-931201-14-1

Entertainment may be another direction for museum transformation. Due to the rapid development of the Internet era, people have more diversified ways of obtaining information, which has led to the fascination of museums. Combining with the content of the museum itself and introducing appropriate design methods, the museum can attract user groups who were not interested in the museum through unique entertainment content. Compared with education, people want more entertaining experiences, and ordinary audiences come to the museum, not necessarily for learning or research, or to gain knowledge or skills. For some people, visiting museums and art galleries is like spending time in a zoo or botanical garden. This change in demand forced the museum to start making changes. Based on the changes in the needs of the audience, the entertainment tendency of museums and exhibitions has been particularly evident in recent years. This is mainly reflected in the museum's increasing emphasis on entertainment effects in the planning of exhibition content. Once the exhibition with entertainment tendency is launched, it will bring a wave of social networking and form a topical phenomenon. With the intensified competition in the industry, traditional museums such as history, natural sciences museums have also begun to conduct research based on the motivation, need, expectation, experience and other emotions of visitors. This prompted the entertainment of the museum to be gradually excavated. This entertainment is not only reflected in the content and methods of the exhibition, such as the immersive experience through AR and VR, but also the social communication activities of the museum, such as "Museum Night" and "Museum Entertainment". When entertainment is popular in the design of museum spaces, we also need to reflect: In fact, entertainment is only a way for museums to attract audiences, but museums must strictly distinguish themselves from other forms of entertainment to fulfil the functions of museums, instead of competing for viewers with other types of entertainment.

At the same time, today's museums also pay more and more attention to the social functions of museums, and they often strengthen the construction of social spaces in the museums during renovation and expansion. Want to meet up with friends over the weekend or find a fun place for dinner with your family? In today's society, museums may become a new option. The importance of social attributes in museums is becoming increasingly prominent. Today, generating social awareness and providing effective visitor services is the prime focus of museums. For fulfilment of these objectives, a museum needs proper strategy and modes of communication outside and inside the museum. The social image of a museum, public interest and accessibility level in the museum is the parameter of success for museums. Nowadays, museums are also changing their communication strategy and modes as per the changing scenario of the society and target visitors.

"In our society today, our museums must promote exhibitions that are topical and challenging; they must broaden their scope and not restrict themselves solely to objects and materials in their collections. Museums must be proactive in their approach to the execution of their mandate and it is important that they clearly explain their vision and mission, which will guide them in all that they do."[1]

1. Arinze, Emmanuel N. "The role of the museum in society." Lecture delivered at the National Museum, Georgetown, Guyana 17 (1999).

3.2.2.4 Conclusion

The research on user experience in space design is still being explored. Although the design theory and framework of product design cannot be fully applied in architectural design, its concepts and research on user experience are of great significance in the design of architectural space. In particular, museum space is a type of space mainly supported by visual experience. Coupled with technological means, virtual reality and augmented reality will use the means or tools of applications and digital products to evolve the museum space to a new dimension. Under the dual role of combining space design and digital products, the importance of user experience is even more important for architects.

3.3 Experience-driven Design Approach in Museum Space

3.3.1 Introduction

Experience design can actually be understood as the user experience design mentioned above. Under normal circumstances, experience design is an interdisciplinary design and service. Any design-related or user-related discipline can involve experience design, regardless of whether the discipline is traditional or digital. At present, the main application direction of user experience design is digital media, but its core element, that is, the user-centred design concept, has broad application prospects in various disciplines, especially the disciplines dominated by design types.

The design of the museum is in line with this design approach. In fact, the core content of user experience is similar to the "Strength, Utility, and Beauty" proposed by Vitruvius in architecture. The museum is a comprehensive public building with the collection, display, education, entertainment, social activities and other elements; Its design must be innovative, contemporary and people-oriented. Only in this way can the modern society's pursuit and expectations of museum functions be met. The museum space will become more attractive and topical when more consideration is given to the needs and behaviors of visitors in the exhibition space and their interaction with the exhibits. Different from traditional architectural space design methods, the user experience emphasizes an iterative design process, designers need to update to meet the diverse needs of users at different stages. The architectural space, The service and experience of museums should be considered in the design of the museum more holistically. Although it may take a long time to change the completed space (such as expansion and renovation) from an architectural perspective, this situation will be revolutionized with the help of virtual vision technology. This section will propose a combination of space design and user experience design, namely experience-driven design approach.

3.3.2 Users, Exhibits and Museum Space

When it comes to user experience, users (that is, visitors in the museum) can be said to be the keywords in this link. The user has different attributes. In the design of museum space, the designer also needs to determine the primary audience of the museum space at the beginning, which makes the user in this space have unique characteristics and become a part of the composition. If a collection space does not involve users, then the collection space becomes a warehouse instead of a museum.

Exhibits are the core of the museum. Exhibits must have unique characteristics to be worthy of collection and display. In museums, users will be interested in participating in the museum space because of exhibits. In the digital age, the information content presented by exhibits may be replaced by the Internet and other application methods, and its most essential authenticity is irreplaceable, which is one of the reasons why users must go to the museum to visit.

The museum's space is used as a place to host exhibits and visitors, and as a critical content of the architect's discussion. How to create a space more suitable for viewing the crowd experience, how to combine the space and exhibits more closely is the architect Need to consider under the user experience-driven design approach.

An excellent museum design requires a reasonable organization of the three elements. The relationship between users, exhibits, and museum space can be explained with the following triple helix (Fig.3.9):

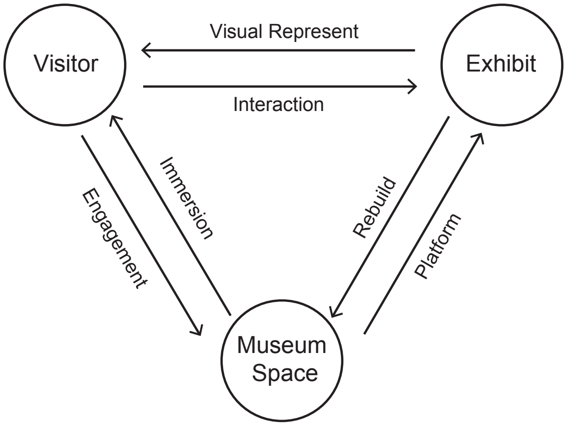

Fig.3.9: the relationship between visitor, exhibit and museum space
Source: Made by author

Visitors interact with the exhibits through various behaviors and means (digital or physical) in the exhibition space. A suitable interaction mode will reduce the sense of distance between the visitor and the exhibits. At the same time, the exhibits will be fed back to them in the form of visual expression. The museum space provides a platform for exhibits. Space presents the exhibits through effective organization. The museum space here has the functions as a container or a platform. The exhibits also gave the building a new form of space. Due to the presence of the exhibits, the attributes of the space have also changed. That means exhibits have rebuilt the museum space. The relationship between the space and the visitor is easier to understand: the visitor participates in the museum space, and what space can bring to the user is to bring the immersive experience to the visitor through design.

Based on the above logical relationship, in the face of ever-changing technological developments, accompanied by the continually escalating viewing needs of visitors and the museum system that continues to self-improve, experience-driven design approach will play a precious role in museum space design.

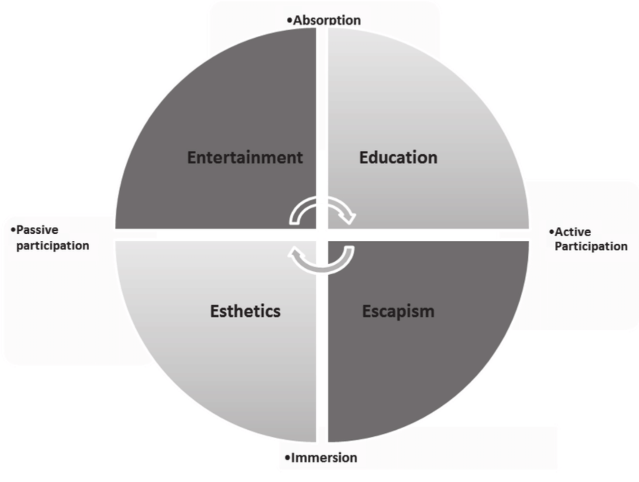

Fig.3.10: Four experience realms, Pine and Gilmore (1999, p.30)

3.3.3 Experience-driven Design Approach

Pine and Gilmore (1999) defined four experience realms in two dimensions (as shown in Fig.3.10). More specifically, the theorists determine whether a consumer (visitors in museums) is actively or passively participating in activities and whether a consumer is absorbed or immersed in these activities. The horizontal axis shows the level of users' participation. At the left end, passive participation means that the user's behavior and participation do not affect the representation of the experience. The other end involves active participation, whereby people are engaged in the experience. The vertical axis describes the connection of the environmental relationship that unites the user with the event or performance. The top end is absorption, occupying the user's attention through bringing the experience into the mental. The other end immersion means the user becomes physically or virtually a part of the experience itself. The four quadrants constructed in the two dimensions are Entertainment, Educational, Esthetic and Escapist.

The four realms explained here coincide with the needs of the museum space. Through this result, we can know which aspect should be dominant in the process of museum design. As highlighted in the previous article, education and entertainment play an essential role in the transformation of museums. It is also a critical requirement that needs to be considered in the space design of the museum. These two elements are consistent with the "Absorption" in the above figure (Fig.3.10). In the museum, the exhibits and the exhibition space together constitute an element that attracts visitors. From the perspective of visitors, they "absorb" the information transmitted by the exhibits and space. And in the level of "immersion", it is defined by two elements "aesthetic" and "escapist" which depends on the activity. It also can be understood if the visitor interacts with exhibits subjectively. When visitors interact passively with the exhibits (usually referred to as passive viewing), the "aesthetic" aspect dominates, and when active interaction occurs, the "escapist" aspect dominates. This kind of "escapist" is the immersive experience in the museum that we have always emphasized.

In addition to the above-mentioned architectural elements, the framework of user experience design still has essential reference value in architectural design. It seems a bit inexplicable to compare architecture to relatively small product design, but in fact, buildings need to be used (whether outdoor or indoor). During use, it will interact with its users to solve a certain problem(s) (such as solving the problem of perfect display of exhibits to visitors in the exhibition hall).

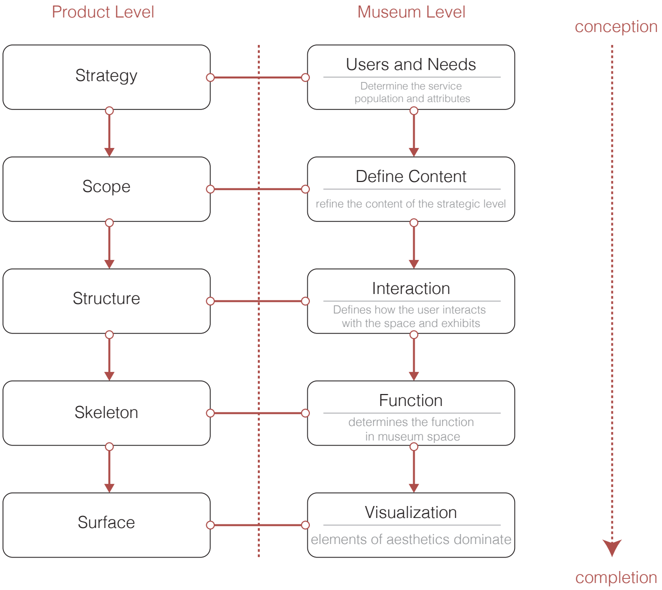

Fig.3.11: Diagram: Experience-driven design approach in museum desugn
Source: Made by Author

This is consistent with the nature of the product. If we consider the architectural space-museum space as a product, its visitors as users, architects as designers, and the value of user experience in its design is self-evident. Relying on the main framework of Jesse James Garrett's user experience elements described above, it can be summarized "strategy, scope, structure, skeleton and surface" (JJ Garrett, 2010) as shown in the Fig.3.11, and its practical significance can be understood explicitly in the museum space as the following:

1. Strategy - Users and Needs:
Before all the design process begins, we need to consider several questions: why do we need this space; who are the users of this space; and if possible, locate the users as accurately as possible (such as who is the primary user group of this exhibition, children, old or college student, etc.); What is the root cause of attracting users to visit; Why do visitors come here; if they can get all the information about the exhibits online. The goal here is to define user needs and museum objectives.

The strategic research process is necessary at the beginning of the design process. Fundamental data is obtained through surveys, questionnaires, interviews, and other forms to understand user needs. Here the architect often needs to do is to balance the different demands of users and exhibitors, and to achieve a balance of opinions from multiple parties through reasonable strategic arrangements. After defining user attributes and museum needs, architects can develop targeted designs for the design of spaces and related exhibits, so that the design results are more likely to attract visitors

2. Scope - Define Content:
Defines functional and content requirements. What are the features and Content contained in the exhibition space or augmented space? The conditions and contents should be a response to the strategic goals as mentioned above.

From the perspective of interior exhibition space, this layer is mainly to gradually refine the Content of the strategic level to determine the Content and form of the exhibition. These contents can even be subdivided into exhibits and auxiliary Content, including but not limited to text, videos, and so on. What also needs to be considered is how space carries the above. In terms of space design, the necessary space form and exhibition form should be determined at this stage, as well as the possibility and potential design difficulties of this form. What is also considered in this part is how to make unique innovations in the display content to ensure the vitality of the museum space.

3. Structure - Interaction:
This level defines how the user interacts with space and exhibits, how the museum space (augmented space and virtual space) changes when the user interacts, how it's organized, prioritized, and how much of it. At this layer, the architect needs to consider how the visitor uses the space, which involves the user's perception of the space. How to properly guide the user to complete the viewing in the space is considered here, and at the same time, the practical organization of the space With the exhibits. That is, the spaces and exhibits are connected by the organization of pedestrian flow lines. At this step, the primary form of the space and the interaction mode between visitors and exhibits should have been initially established. And started looking at improving user experience with

digital technology.

4. Skeleton - Function
Skeleton determines the function in museum space. In this layer, At this layer, the function of the exhibition space should be gradually improved, and some basic settings and exhibition elements should also be designed and completed. At this time, visitors should be able to see the exhibits. Although these exhibits may not be presented to visitors in the best form, the core content of the exhibits and the functions of the related digital equipment should be complete. Visitors should be able to view the exhibition generally at this time, although the experience may be slightly lacking.

5. Surface - Visualization
As the final level, this is a summary and synthesis of all previous work. It determined how did space and augmented will look like, and choosing the right layout, volume, material,...etc. In this level, At this level, we pay more attention to the architectural visualization and aesthetic representation of museum space. It should not only make things easier to understand, increase cognitive ability to absorb what users see in the museum, but more able to convey the aesthetic ideals and artistic criticism of designers and architects. Through more design that fits the user's aesthetic orientation, the experience of the museum space is finally formed by the dual aesthetics of digital media technology and real space.

User experience plays a pivotal role in the design of today's digital products. Despite the rapid pace of technological advancement, its fundamental principles and framework are still valid and can guide designers to make better designs. Virtual vision technology helps users to experience the sufficient support of trust and immersion from the technical level and confirms the feasibility of the service framework of user experience design proposed by Jesse James Garrett to this day.

3.4 Conclusion

The research on user experience in space design is still being explored. Although the design theory and framework of product design cannot be fully applied in architectural design, its concepts and research on user experience are of great significance in the design of architectural space. In particular, museum space is a type of space mainly oriented on visual experience. Coupled with technological means, virtual reality and augmented reality will use the means or tools of applications and digital products to evolve the museum space to a new dimension. Under the dual role of combining space design and digital products, the importance of user experience is even more important for architects.

It is feasible to use experience-driven design approach as in modern museum space design. Based on the extensive use of virtual and digital technologies in modern museums. It is foreseeable that digital products, especially augmented exhibits and virtual experiences, will gradually increase in future museums. The core of this digital product can rely on the experience-driven design approach. And from a spatial perspective, this design approach can still play a role. Pay more attention to the visitors' personal attitude in the museum space. From the perspective of experience, it is supplemented by technical means and augmented exhibits. It is one of the best choices for a contemporary museum to enhance self-attraction and contribute social value.

3.5 Short List of Bibliography

1. Adlin, Tamara, and John Pruitt. *The essential persona lifecycle: Your guide to building and using personas.* Morgan Kaufmann, 2010.
2. Arinze, Emmanuel N. "The role of the museum in society." *Lecture delivered at the National Museum, Georgetown, Guyana* 17 (1999).
3. Boylan, Patrick, ed. *Museums 2000: politics, people, professionals and profit.* Routledge, 2005.
4. Deaton, Mary. "The elements of user experience: user-centered design for the Web." *interactions* 10.5 (2003): 49-51.
5. Garrett, Jesse James. *The elements of user experience: user-centered design for the web and beyond. Pearson Education*, 2010.
6. Hansen, Ann H., and Lena Mossberg. "Consumer immersion: A key to extraordinary experiences." *Handbook on the experience economy.* Edward Elgar Publishing, 2013
7. Janson, Alban, and Florian Tigges. *Fundamental concepts of architecture: The vocabulary of spatial situations.* Walter de Gruyter, 2014.
8. Sutherland, Ivan E. "The ultimate display." *Multimedia: From Wagner to virtual reality 1* (1965).

CHAPTER 4

NEW MUSEUM FORM THROUGH VIRTUAL EXPERIENCE

4.1 Introduction

This part of the article will gradually explore the new form of spatial pattern in the museum under the influence of virtual technology. Virtual technology, virtual exhibits and space (including tangible space and virtual space) together constitute a new form of spatial pattern, which can be classified into interactive space, augmented space and full virtual space according to the ratio of virtual exhibits to real exhibits. This new spatial component redefines the relationship and experience between users and space, and gradually changes the museum from visually dominant to experience-led.

Based on this change, this chapter will also explore the essential relationship between reality and virtuality in the museum space, spatial perception and experience change. At the same time, it will also put forward the thinking about the authenticity of space, which will reflect the design trend and value of museum space in the future. With the rapid development of virtual vision technology, online-based virtual museums have impacted the real museum space. The Covid-19 epidemic has made this virtual space and communication space face the implications of social topics once again. In this chapter, it will redefine and discuss the meaning of museums in the digital age.

4.2 Digital Exhibit, Interaction Communication and Interaction Spaces

4.2.1 Introduction

Digital exhibits refer to all non-physical exhibits and content, such as electronic images, projections, touch screens, augmented reality and virtual reality. The most significant advantage of digital exhibits in the museum space is that it is easier to reach and interact with visitors, whether active or passive. The most basic interaction model is visually-based passive interaction (here mainly refers to the playback of digital images and videos). With the evolution of digital models, the number of interaction methods has gradually increased, and there will be some new different experiences brought by digital exhibits. Despite the inherent property of mechanical reproduction, digital exhibits may be observed ubiquitously. While museum space provides authentic space with experiential value, the organic combination of museum space and digital products will upgrade exhibition space. While visitors interact with the exhibits, these behaviours, cognitions, feelings and experiences together upgrade the museum exhibition space and turn the exhibition space into an interactive space.

As visitors, their curiosity is actively mobilized in the museum space. Today, we live in an era filled with digital elements. Cell phones, computers and smart devices permeate all corners of our surroundings. Diverse digital media and interaction methods have redefined the logical relationship between the visitors and the digital exhibits, and visitors have increasingly demanded interactive experiences. The interactive way of "seeing" in the museum space is slightly behind in the eyes of the development of the times.

AR and VR dissolve the sense of boundary between the virtual world and the real world, which provides potential possibilities for creating immersive interactive spaces. The change of space and the possibility of interaction have given the architect an experiment site for design talents. It is also because the means and tools for creating space are being enriched, and the participants in space experience changes in the form of space. This is helpful for the increase of participation and attractiveness of public space such as museums.

4.2.2 Digital Exhibit and Augmented Exhibit

The augmented exhibit is one kind of exhibit using the image, video, or interactive 3D model that is constructed with digital means and real-world interaction logic. In recent years, especially after the widespread adoption of smartphones, more and more exhibitions have offered this new way of exhibiting a seemingly empty showcase or place that can be used a smart device to simulate a digital object or space.

Unlike traditional digital media such as led screens and projection displays, augmented exhibit have the following properties: combines real and virtual objects in real space or environment; runs interactively, and renders in realtime, then aligns real and virtual objects with each other. As a visually-oriented public space, exhibition space is most suitable for augmented reality which is also a visually-oriented new technology.

Augmented exhibits use digital technology to present a viewing experience that is highly interactive with the real world. Augmented reality sees technology allow the overlapping of the virtual world with the environment around us. The possibilities are plentiful with Augmented reality because it imitates what our imagination does aka. When we imagine things, we add characters, objects and other elements to the real world, just like Augmented reality does. According to its mode of changing content, augmented exhibits can be roughly divided into the following four categories:

1. Replacement:
The replacement mode refers to replacing objects existing in the real world with virtual objects through AR technology. The replaced objects can be two-dimensional planar objects such as pictures, or three-dimensional objects in the real world. Digital exhibits (pictures, videos, or interactive 3D models) will replace the preset objects in the original space. The result of this replacement will be fed back to the user through the display layer of a digital device (usually a smart device such as a handheld mobile phone).

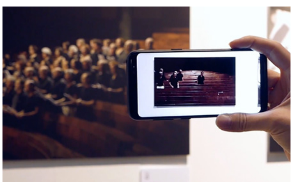

Fig.4.1: Living Image. viennacontemporary art fair, 2018
Source: https://www.viennacontemporary.at/en/living-image-2018/

The picture on the left (Fig.4.1) shows the possibility of an alternative mode: a exhibition named "Living Image" which held in viennacontemporary art fair in 2018. *[...] Living Image presents, in cooperation with the mumok exhibition, videos of artist's musical performances. Concert recordings of the mumok exhibition are* *presented together with selected contributions of the fair's open call. Using the Artvive App transforms the film stills into moving images.*[1] In the above case, AR technology was involved, replacing two-dimensional pictures in the ex-hibition space with videos created digitally. This exhibition method has significantly improved the enthusiasm and exploration of visitors.

1. https://www.viennacontemporary.at/en/living-image-2018/

The demand for museum experience quality from traditional museum audience is increasing. *Visitors are no longer willing to be passive recipients of wisdom from on high, but want to participate, to question, to take part as equals, and to receive as high a standard of service as would be offered at any other type of leisure site. (Hooper-Greenhill, 2007).* The new exhibition method encourages visitors to use smart devices to "replace" the existing space exhibits. Curiosity and additional information drive visitors to "scan" the next exhibit, expecting different "replacements" to appear on the mobile screen. Although it does not make drastic changes to space, it can effectively enhance visitors' enthusiasm and exploration in the exhibition space.

2. Additional:
Adding models means adding additional information and content to the original exhibits through augmented reality technology. The added content does not change the original exhibit but appears in the visitors' vision as a floating message. Exhibitions in traditional mode can easily ignore text messages, especially for art museums. Given that the user groups who visit art museums are not necessarily those who are engaged in professional fields (in fact, most visitors to art museums are not art professionals), reading and understanding artworks often require additional information. This information usually It is attached to

Fig.4.2: Entrance to Epic Abstraction exhibit at Metropolitan Museum of Art with Jackson Pollock's Pasiphae.
Source: https://www.forbes.com/sites/chaddscott/2018/12/30/jackson-pollock-and-superstars-of-abstract-expressionism-on-view-at-the-met/#47492e3528aa

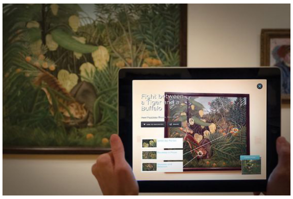
Fig.4.3: Cleveland Museum of Art
Source: https://www.clevelandart.org/

the artwork in the form of text, and the text is often not valued for various reasons (text position, size, etc.). As shown on the left (Fig.4.2), the location of the text information (indicated by a red circle) in this museum space is not noticeable. Compared to large-format artworks, the text position and size are not easy to read, which is not a pleasant experience for visitors, especially those who want to learn more about artworks.

However, augmented content created using AR can effectively address this experience disadvantage. When a visitor scans a work of art using an AR device, the corresponding detailed information will appear on the device in the form of floating information. In addition to text, the information can also be made into audio or even video. As shown on the left (Fig.4.3), visitors can instantly scan the artwork in the Cleveland museum to get information on how to appreciate the artwork better. Under AR's effect, floating information can accurately locate the information that appears in different parts of the artwork. This kind of detailed information interpretation is beneficial to complete the museum's education goals.

Additional information in the AR environment can respect the original exhibits as much as possible, and display more contents with good readability without changing the original exhibits.

3. Disintegration:
A common situation in museums is that many exhibits have strict protection requirements, and visitors can only view the exhibits through glass boxes. The "disintegration" mode of augmented exhibits can help visitors break this protective shell through the combination of digital form and real space, and have

the opportunity to bring visitors "into" the exhibits to explore. This "disintegration" approach to augmented exhibits is often used in more extensive antique exhibits. For example, the Detroit Institute of Arts (DIA) has premiered a mobile tour called Lumin that uses Google's Tango technology to provide visitors with new, in-depth ways to engage with the DIA's renowned collection. The DIA is the first art museum to integrate this 3D wayfinding and smartphone augmented reality (AR) technology into a public mobile tour. Among them, Egypt's mummy exhibits are impressive to visitors (as shown in Fig.4.4). With the app's AR overlay, visitors can peer beneath the sarcophagus and even the mummies' bandages to explore an X-ray-like view of the skeleton.

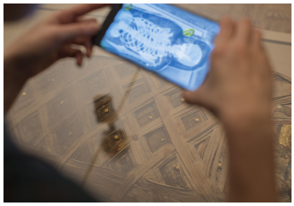

Fig.4.4: Detroit Institute of Arts
Source: https://www.dia.org/

This exploratory exhibition approach has narrowed the relationship between visitors and exhibits, and "breaks" the shell of the exhibits through interaction and experience. As DIA director, Salvador Salort-Pons, said: *" Augmented reality allows the user to see the unseen, imagine art in its original setting and understand how objects were used and experienced in people’s everyday lives. It is an exciting way to incorporate the latest technology into the visitor experience."*

4. Creation:
"Creation" is another kind of virtual experience that augmented exhibits can provide to visitors. Virtual objects appear on the device in a digital form. From a user experience perspective, visitors see digital exhibits appearing in real space through the device. Different from the above method, the "creation" mode does not rely on physical exhibits in reality, and only requires existing space to display virtual objects to visitors. This "creation" mode gives designers a great

deal of freedom to create virtual digital objects, but this freedom also brings specific problems: how to make a proper connection with the existing physical space. The virtual "creation" without physical space loses the original experience in the museum space. If this virtual exhibit can be viewed anywhere, and it does not bring freshness in the dimension of the experience, this "creation" mode Is failing.

"Casa Batlló Museum" can be seen as a successful example. Casa Batlló building, Located in the heart of "Passeig de Gracia" in Barcelona, the work of the Catalan architect Antoni Gaudí stands out for the way it integrates new technologies and augmented reality in the experience of its visitors. Inside the building, the users could enjoy augmented reality experiences, virtual environments, and 3D animation. Visitors could discover how the Batlló Family lived in the Barcelona of their era, what the furniture was like in the elegant ground floor, and how the building's organic and natural forms also came to life. This augmented exhibit, which is closely integrated with the original space, is a novel experience for visitors (as shown in Fig.4.5). The original real space did not have many furniture and objects, but under the effect of augmented exhibits. These virtual objects created are furniture furnishings that were once in the original space. This experience with a high degree of relevance to the original space is at the key of the "creation" model.

Fig.4.5: Casa Batllo and its AR application
Source: https://www.casabatllo.es/

Overall, augmented exhibits offer visitors more possibilities than traditional exhibits. Exploratory improvements can make visitors more willing to discover and understand exhibits. Digital exhibits have stimulated the curiosity of the visitor community. Curiosity and desire to explore allow users to better use their design and exhibition value in the museum space.

Entertainment is also a prominent feature of enhanced exhibits. Augmented exhibits often use applications to complete the connection between visitors and virtual exhibits. This connection has entertainment that allows visitors to participate in these applications more widely. In addition to its core functions of collection and display, functions such as education and entertainment are also expected to be museums' duty and social responsibilities in the Internet era. More participation means a more active museum space, which will help strengthen the multifunctionality of museums.

As a digital exhibit, it has a non-negligible advantage. Compared with physical architectural elements, it can quickly update and customize content based on museum content. This update and customization can be targeted to adapt to the rapid development of the era, and applications and virtual content can be changed in a timely manner based on user comments and feedback. The cost may require designers to continuously participate in their entire design cycle. The consumption of human and material resources may be a potential problem for digital products.

4.2.3 Augmented Space

"Augmented Space" is first mentioned in Lev Manovich's article "The poetics of augmented space" (Manovich, 2006), he defined augmented space is the physical space overlaid with dynamically changing information (Manovich, 2006), and argues that augmented space is a new paradigm with its logic and implications. In his concept, augmented space is described very broadly, including standard digital media such as the cinema screen, the TV screen, the computer monitor, etc. It seems that the shallow overlaying data layer can no longer be called an augmented space element in 2020 which is information technology has penetrated every aspect of our daily lives. The article by Manovich about augmented space was written in 2002. For the article with technological change as its core driving force, significant changes have occurred in the technological development in the past 20 years. Given this, augmented spaces also need to be updated continuously and re-conceptualisation.

The advancement of AR technology has given us a new understanding of digital media and virtual elements and has also given us a deeper understanding of the connection between the virtual world and the real world. The development of real-time rendering and interactive methods offers the possibility to enhance immersive experiences in the real physical world. Designers use these virtual elements to augment the existing original space and upgrade the original space into an augmented space. Augmented space has developed rapidly in the digital age today and has the following characteristics: the fusion of virtual elements and real space, the similar interactive behavior to the real world and the changes in cultural perceptions of existing spaces.

1. The fusion of virtual elements and real space:
The definition of augmented space by Manovich is *"augmented space is the physical space overlaid with dynamically changing information"* (Manovich, 2006). This kind of "dynamically changing information" can be understood as virtual elements created by augmented reality technology. Virtual elements and real space are fused and intertwined under the action of AR components. These virtual data do not appear as independent elements on display devices (such as screens). Instead, these data and information are placed in the real environment space, the boundary between the real and the virtual is eliminated by this

kind of fusion, and the virtual elements and real space are finally combined in a natural way.

The augmented space in the new era's context is gradually dissolving the sense of boundary between digital media and the real world. Digital media technology used in spaces, especially in exhibition spaces, most often appears on display screens. Such screens can be considered an augmented experience in the early days of virtual elements. However, as human understanding of digital and virtual progress, the screen is gradually regarded as a picture or video frame. The sense of boundary brought by this frame has been out of the category of "augmented" in the new era.

The blurring, even eliminating borders benefits from technological advancement. The processor collects real-world visual information, then fuses digital information and virtual objects with the real world through overlaying to form the basis of augmented space. This overlaying is different from covering, which means that visitors will receive the real world as a background layer. However, the covering layer, which virtual objects obscure the content of real space, loses its interaction with real space. In the end, this overlayed real-time rendering is fed back to the visitor through the visual mode, and the visitor finally gets a prototype of essential augmented space. This fusion brings an increase in the vitality of real space and the possibility of immersion.

2. The similar interactive behavior to the real world
Immersion is one of the main goals of augmented space, and it is also an essential reference and way to improve user experience in museum space. The sense of immersion can be understood as a sense

of deception, which mainly deceives visitors through visual means, and "brings in" visitors from real physical spaces to "traps" designed by architects. This "trap" is the space transformed by the design method, and the transformation space under the blessing of digital technology is the augmented space. To "deceive" visitors with this immersion, a similar interactive behavior to the real world is necessary.

In museum space, movement and observation are the most critical interaction behaviors in the real environment. The visitor's vision continually changes with the displacement, thereby observing different exhibits and different perspectives of the same exhibit. In contrast, in the digital age, our interaction with the media is entirely different. Digital media platforms define the medium between the user and the virtual element. This medium often uses "anti-realistic" interaction methods. The following example can make the explanation clearer: In the real world, if we want to look at an object more closely, we need to move to approach the object. Then in our vision, this object is "magnified". In the interaction with digital media, if we want to "zoom in" on an object, the operation on the touch screen is usually "stretch". Similarly, if we want to see the back of an object, we need to move to the back of the object or rotate the direction of the object. In digital media, we need to rotate the virtual object by touch or mouse.

This difference in interaction behavior exacerbates the sense of boundary between virtual and reality. In order to implement the immersion into the augmented space, virtual objects with real-world interaction behavior are the core elements for creating this immersion. Thrift described the link between real time electronic data and the real environement: *"as a result of the* *intervention of software and new forms of address, these background time-spaces are changing their character, producing novel kinds of behaviours that would not have been possible before and new types of objects which presage more active environments."* (Thrift, 2004)

Thanks to advances in related technologies such as real-time rendering, real-time localization, and spatial perception, augmented reality technology can already bring this real interaction to virtual objects in a low-cost way. These interaction method and logic are producing augmented space as an egocentric subjective environment (Nold, 2009). Grau also made similar opinion:*" the panoramic view is joined by sensorimotor exploration of an image space that gives the impression of a 'living' environment, interactive media have changed our idea of the image into one of a multisensory interactive space".*(Grau, 2003). It is foreseeable that powerful computer computing capabilities, cloud processing capabilities and network terminals will continue to improve. On this basis, the virtual objects in the augmented space will become more and more realistic, both in terms of representation and interaction. In the future, more augmented spaces will be created, waiting for people to participate and activate.

3. The changes in cultural perceptions of existing spaces

Space in the traditional sense generally refers to the concept in the geometric sense, that is, a limited geometric shape constructed by architectural elements. Augmented space not only emphasizes its real space in the physical sense, but also focuses on human behavior and experience in space. As Egenter wrote: *"Space was not there from the beginning, as*

1.Egenter, Nold. "Otto Friedrich Bollnow's anthropological concept of space." 5th International Congress of the 'International Association for the Semiotics of Space', Hochschule der KYnste Berlin. 1992.

we assume with the Euclidian concept. Space in the human sense has evolved. As a concept related to human perception and culture, it was originally closely related to dwelling and settlement and subsequently developed by extension of the spatial perception of man" (Egenter, 1996)[1].

Due to the involvement of virtual elements in augmented space, the user's experience and behavior in space has become significantly different from traditional spaces. This change in spatial cultural cognition determines the difference in attributes between the enhanced space and the real physical space. Augmented space is not just a container, a shell, or a specific location, but a place where users participating in it act, experience, and communicate together. Human perception of space and cultural cognition is closely related to the meaning of the augmented space. Movement, behavior and experience together redefine space. According to Crabtree's explanation in sociological perspective, *"the relationship between space and technology is a practiced one, in other words behaviour is what shapes place."* (Crabtree, 2000). In other words, new technological, social and cultural paradigms, experience and behaviors, real physical environment together form the new augmented spatial type.

We can use augmented reality to create virtual objects. These virtual digital objects interact with users engagement in space activities and create augmented space. This new form of spatial pattern contains real physical environment, virtual objects that behave similarly to real interactions, user experience, social practice and cultural perceptions in digital era.

4.2.4 Virtual Space

Virtual space can be understood as the extreme form of augmented space. As mentioned above, augmented space refers to adding virtual elements to real space and maintaining its authenticity and credibility in physical space. When such virtual elements continue to increase, and eventually, the entire real space is completely covered, the augmented space is transformed into a virtual space. The definition proposed by Milgram and Colquhoun, which describes AR from a perspective of the mixture of real and virtual environments. According to them (Milgram and Colquhoun, 1999), real and virtual environments are not merely alternatives to each other but preferably two ends of a Reality-Virtuality continuum (Fig.4.6). The AR section starts from the real environment end and expands towards the virtual environment and its counterpart originating from the virtual environment extreme is named augmented virtuality (AV). Both AR and AV make up the mixed reality, which accounts for the entire continuum but the two ends.

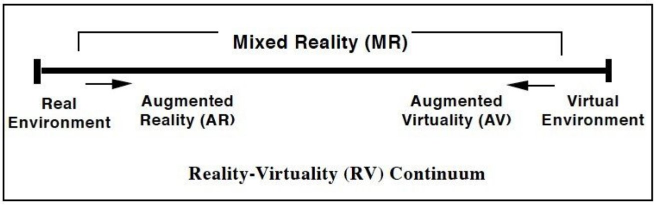

Fig.4.6: A taxonomy of real and virtual world display integration by Paul Milgram and Herman Colquhoun.Mixed reality: Merging real and virtual worlds, 1:1–26, 1999

From a technical view, virtual spaces require an utterly immersive experience environment, at least from a visual perspective. This means that the head-mounted experience device is the best platform for creating a virtual space under current technical conditions. This head-mounted device will completely obscure the visual information conveyed in the real space that the user can see with his eyes, and replace it with the created virtual elements which fill the user's entire visual range. VR technology, as one of the most popular technology categories at present, is an excellent technical solution for creating this virtual space, according to different needs and technical costs. The virtual space it creates can be divided into two categories: static and interactive.

Static virtual space means that when the user enters the virtual world, except for the visual information of the certain observation point, users cannot make any other interaction with the virtual world. The creation cost of this kind of static virtual space is low. It is essentially an immersive way to view 360 ° panoramic pictures. Use the gyroscope to feel the user's line of sight to achieve a similar real viewing experience. The creation cost of this kind of static virtual space is low. It is essentially an immersive way to view 360 ° panoramic pictures. Use the gyroscope to feel the user's line of sight to achieve a similar real viewing experience. The disadvantages are also prominent, such as being unable to move the location, not interacting with the virtual elements in it, and so on. Nevertheless, static virtual spaces are widely used in various museum scenes due to the cost-effectiveness of equipment and creative costs.

The interactive virtual space is more in line with the definition of virtual space in the minds of people. As *Or Ettlinger* mentioned*:"virtual space is made up of countless virtual places, and any respective object included within them is then, by definition, located in virtual space – or in other words, it is 'virtual'."*(Or Ettlinger, 2008)[1]. Continuous virtual positions together constitute a virtual space. In this virtual space, users can move freely. As the position changes, the panoramic image generated by real-time rendering changes at any time. This can be understood as:

1. Ettlinger, Or. "In Search of Architecture in Virtual Space." Slovenia: University of Ljubljana (2008): 64.

the myriad, continuous static virtual spaces are merged together to form the prototype of interactive virtual space. That is like Sophia Psarra said*:"the relationship between geometric and spatial properties can be understood as based on the varying degree of geometrical control over the potential for variance in the structure of visual fields observed with bodily movement"* (Psarra, 2009)[2].

2. Psarra, Sophia. "Spatial culture, way-finding and the educational message: the impact of layout on the spatial, social and educational experiences of visitors to museums and galleries." Reshaping museum space. Routledge, 2005. 92-108.

The continuity of scenes is only a basic representation of an interactive virtual space, and a virtual space with multiple interactive behaviors and interactive virtual objects may bring more immersive experiences to users. With the help of an external device similar to a gamepad, users can simulate their own hands in the virtual world through the positioning device, and use it to complete the corresponding actions in the virtual space. This deeper level of interaction goes beyond passive visual reception, adding feedback through actions and haptics (hand-to-joystick touch). This brings more entertainment and exploration in addition to more immersion in the experience of virtual space.

From a content view, as a type of new architectural space, virtual space can also be understood as a platform for carrying space content. And during use, the virtual space provides the possibility to completely replace the real physical space, which can allow a higher degree of freedom in creating content. According to the relevance of its content to the real physical space, virtual space can be divided into the following three types:

1. Simulation / Recovery:
Simulation and recovering based on real space can be regarded as the first stage on the content level of virtual space. As we know, many museums

provide virtual museums for users around the world to experience. For example, *"The State Hermitage Museum located in Saint Petersburg Russia now provides its worldwide visitors to experience its new virtual reality educational entertainment platforms. This VR experience includes 3D models of the famous exhibits—the Italian Skylight room and Jupiter room, and a 360 VR video about the history of the Hermitage Museum starting from time period of Catherine The Great. All these VR entertainments can be viewed through HTC VR headsets."*[1] Based on VR technology, this virtual experience is not limited to viewing exhibits on computer web pages, but also to restore the museum space as much as possible. Use VR glasses and other devices to bring visitors into the simulated museum space.Visitors can enjoy high-precision exhibits and their details without leaving home, and more importantly, feel the charm of the museum's architectural space. In this kind of virtual museum space, its virtual content is basically completely produced by real sampling or modeling. This complete restoration of real space is the most common form of content expression in virtual space (as shown in Fig.4.7).

1.https://cie.acm.org/articles/virtual-reality-hermitage-museum/

Fig.4.7: Visitors is using VR set in museum

Recovery explains the possibility of virtual space, reflecting the content of real space from another dimension. For various reasons such as inevitable natural disasters, war damage, etc., the historical architecture may not be represented to people in their most complete and glorious state. The virtual space can give visitors the closest real experience by completely recreating the historic building. With the gradual maturity of 3D scanning and related technologies, more and more historical sites and protected buildings can wait for visitors to explore through virtual space. This can also be seen as digital protection and inheritance of historical and cultural heritage. VR experience of Notre-Dame could be an excellent example of Recovery using in virtual space. Since the Notre-Dame cathedral's roof and spire were destroyed in a fire, it has been closed to the public. But Rebuilding Notre Dame[1] will take you back inside one of the world's great monuments, both before and after the flames.

1.Rebuilding Notre Dame is a new documentary in VR created by Targo, capturing the cultural landmark in 360-degree video as it looked before April 15, 2019 and where the reconstruction stands now.

Simulation or Recovery as a replica of real space in the virtual world, this experience helps visitors to approach the immersive real presence when they can't be there. And provide high-reduction digital literature in the cultural heritage of historical buildings. There may be some people who wonder that if real space will replace by high-fidelity virtual space. In fact, the purpose of virtual space is not to replace the experience brought by physical space. *"The aim is not to replace the real experience, but to integrate it with data and explanations not physically available during the visit, thanks to a multi-channel communication which, unlike the symbolic-reconstructive single-channel communication (characteristic of the written text), is more natural for the human being and improves the understanding, learning and diffusion of knowledge."*[2]

2.Agnello, F., F. Avella, and S. Agnello. "Virtual reality for historical architecture." International Archives of the Photogrammetry, Remote Sensing & Spatial Information Sciences (2019).

2. Creation:

Thanks to virtual reality technology and equipment, immersive space is more likely to be created by designers and architects through digital tools. It is true that 3D artists and modelers are usually more focused on the creation of 3D content than designers and architects with general backgrounds. However, in the creation of AR and VR experiences and content that tend to interact with real logic, architects have the understanding of real space and expertise to create virtual environments more effectively. Therefore, creation can also be considered as an important form of virtual space content. There is a fundamental difference between creation and simulation, even though both require "making" a virtual space in a digital medium. Creation here refers to providing a new digital virtual space without relying on real scenes. In the digital world, architects can no longer be constrained by building materials, and the cost of construction builds their ideas about space in the closest real way through vision and some simple interactions. These created virtual spaces can be divided into two categories based on their physical properties.

The creation of the first type of virtual space is based on real physical laws and the gravity system. The space created by the architect completely matches the space that visitors come into contact with in daily life. This kind of creation can be understood as an extension mode of real space. Its spatial law is almost the same as the essential core and traditional space mode. The difference lies in the fact that the form of expression is transformed into a number. In the virtual space, the architect can abandon more restraints, complete his more understanding and ideas of space, and bring this digital form of space and experience to visitors. Furthermore, architects can use this virtual model for experiments and research on architectural space. Because digital model changes and adjustments are more convenient and dynamic, virtual spaces based on digital models have more diverse changes. Through the experience changes brought about by different parameters of the space, users' behaviors and activities in the virtual space can help architects better understand the role of space for visitors. Virtual reality technology is not only a tool in shaping virtual space but also a platform and future experience mode, which is especially crucial in exhibition halls and museums that have been driven by the experience.

The second type of creation in virtual space depends entirely on the creativity of architects and designers. One of the advantages of the virtual world is to create a completely closed and independent virtual environment, which means that the created environment can break away from all physical laws and space-time restrictions of the existing world. This gives architects and designers great creative freedom, and they can use VR tools to complete the maximum visualization of their imagination. This non-realistic space based on imagination is commonly seen in science fiction, films and video games. There is also a similar representation of "impossible space" in early artworks, and the typical representative is Escher's related works. For example, in his drawing Relativity (Fig.4.8), Series of staircases and architectural elements, including furniture and details, appear polarized around the centre of vision, each one affected by a proper gravity force, as the orientation of the human figures walking from point-to-point suggests. According to the title of the work, each person in the scene is supposed to see the space from her/his "relative" point of view. While the light coming from above beyond the upper limit of the represented scene stabilizes our "external" perception, providing a practical visual orientation to our sight. This kind of space and environment obviously violates the laws of physics in the real world and cannot appear under the existing gravity system. The virtual space provides an opportunity to create this "impossible space". This is also a new feature that virtual technology can show. Furthermore, the virtual space even allows users to enter the "impossible space" created by the artist or architect from a new immersive perspective.

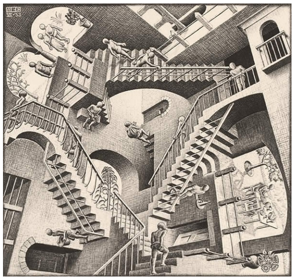

Fig.4.8: M.C. Escher, Relativity, Lithography, 1953 MoMA, New York, USA

Virtual space breaks the context of traditional space. It is not so much "breaking" as it is a kind of "renewal." Facing this new form of space, architects and designers have more means and design elements. The update of building materials and technology has brought about a revolution in space and form (such as super high-rise buildings and non-linear buildings). It is foreseeable that virtual space gives architects more than just a tool, but almost unlimited exploratory and possibility.

4.2.5 Communicative Interaction Space

Communicative Interaction Space (CIS) in the context of the digital age refers to a space filled with one or more digital virtual elements, and the virtual elements interact with visitors in the space, then the interaction results will affect other visitors and the orginal space. Interaction is the future, to be precise, the protagonist in the digital age. As Carlo Ratti explained*:"A living, cybernetic program in spaces of dynamic interaction will make architecture more like an extension of the body—and it is cyborg 'tools' that enable the environment to respond. Augmented or 'living' architecture is the large-scale hardware that digital-physical cyborgs create, plug into, and interact with.[…]Ultimately, technology recedes into the background, and interaction is brought to the fore. Buildings can be simple—rather than voluptuous and shocking—but even more integrally vibrant and living."*[1] Technology, original space and augmented space together form the cornerstone of the CIS, which is different from traditional architectural space. The interaction between traditional architectural space and its users is usually passive, especially in public spaces like museums with static exhibits. Static here does not mean that the audience can only stand at a fixed

1.Ratti, Carlo, and Matthew Claudel. The city of tomorrow: Sensors, networks, hackers, and the future of urban life. 2016, P44.

angle to appreciate the exhibits, but it means that the audience can only receive the information presented by the exhibits unilaterally. In this context, the museum space and exhibits are unable to effectively perceive the user's engagement and provide corresponding feedback. In fact, in museums, if visitors are allowed to interact with exhibits at a deeper level (such as touch screens or other devices) when the next visitor uses it again, it will often be restored to its original state by staff or preset procedures. Simply put, for different user groups, no matter when they enter the museum, their experience is always similar. In the future, this passive experience relationship will be entirely changed by CIS.

We can use a more life-like situation as a metaphor: CIS and the experience of traditional space correspond to our browsing news on the Internet and traditional media such as newspapers. The text in the newspaper is the same for every reader, and every user can get similar information from it. The Internet gives users more choices, and according to big data, the Internet will also push different customized information to users according to their preferences and concerns. Although this model has received some critical voices, critics believe that this model has kidnapped users' self-will. But in fact, this customized model based on big data is becoming more and more popular under the framework of the Internet of Things. Space experience will also undergo similar changes in the future. Space is not only a one-time subjective expression of the architect but also a customized expression according to different user groups and user preferences.

In the CIS, The interaction between visitors and space and exhibits is active and changeable. This change can be based on the visitor's own attributes (for example, users of different ages could see various virtual or augmented content), or based on the visitor's behavior (for example, in the face of other actions detected based on motion capture, the augmented space will change accordingly), and even visitors can change the augmented space to become part of the creator. Just imagine if users can participate in the space design, their behaviors and feedbacks can be collected in time through big data, and architects can use these data to update their strategies in time. Building renewal in the usual sense is a prolonged process. Renovation and expansion can often last for several years. This speed seems a bit too slow in the Internet age. According to the statistics of the Apple App Store, the application will be updated every 18 days on average. 75% of the applications have been updated more than 25 versions. These data show that the habits and demands of users will change at any time. In order to adapt to the trend of this era, applications must frequently upgrade and update themselves. The CIS based on digital elements can also be updated like an application. With the support of big data, space theory and indoor exhibition strategies will be quickly renovated under the guidance of architects according to user needs and feedback. Architects need to start to rethink the criticism and reshaping of the nature of space brought about by digitalization. As William J. Mitchell in his book writed: *"For millennia architects have been concerned with the skin-bounded body and its immediate sensory environment[…]Now they must contemplate electronically augmented, reconfigurable, virtual bodies that can sense and act at a distance but that also remain partially anchored in their immediate surroundings."*[1]

1.William J. Mitchell, City of Bits: Space, Place, and the Infobahn , 1996, P43

4.2.6 Conclusion

AR and VR dissolve the sense of boundary between the virtual world and the real world, which provides potential possibilities for creating immersive interactive spaces. The change of space and the possibility of interaction have given the architect an experiment site for design talents, and they can continue to stimulate visitors and make them more willing to engage in such spaces. Based on AR and VR, the museum gives birth to augmented exhibitions and virtual experiences, which are different from traditional museum spaces. *The rise of new technologies incrementally erodes the form, function* (De Cindio and Aurigi, 2008). New technologies have brought new spatial forms. Under the effect of virtual vision technology, the new spatial forms can be summarized as augmented space, virtual space and communicative interaction space. These new forms of space put forward new requirements for architects, and also challenge and criticize traditional space modes. The essence of space has become more prominent under the effect of digitalization.

4.3 Reality and Virtuality in Museums

4.3.1 Introduction

The degree of fidelity of virtual exhibits may reach the level of false realism in the near future. In this case, how likely is the acceptance of virtual exhibitions and digital products in museums? The core function of museums is collection and display. Although many museums have launched online functions and published their high-resolution exhibits on the Internet, this does not seem to obliterate visitors' enthusiasm for visiting real museums. The development of social life and technologies have brought about continuous changes in aesthetic culture, which are manifested in the constant dissolution of traditional boundaries and the gradual rise of virtual vision technology. This requires various cultural organizations to change their previous educational postures and seek new relationships for interactive dialogue. Reality and virtuality are relative concepts. Augmented reality and virtual reality try to dissolve the boundary of this relative concept through technical means and merge the two together. Due to the tremendous pressure of transformation and development of museums, its social role has also changed in accordance with the development of social aesthetic culture in the digital era. In this section, the article will rethink authenticity. This is not only about the "aura" of the artwork itself, but also discusses the new authenticity of space as architectural art.

4.3.2 Authenticity

4.3.2.1 Authenticity in Musuem

As an important cultural institution, museums play an irreplaceable role in the inheritance and dissemination of historical culture. However, the continuous development of social life has brought about continuous changes in people's cultural consumption needs, and the exhibition methods of museums also need to be adjusted continuously with the changes of the times to adapt to the new conditions of the people and the new challenge of technologies. Only by fully understanding the characteristics of the digital society and authentic consumer needs can we provide the right direction for the transformation and development of museums. "Authenticity" is a particularly important attribute of cultural heritage. Therefore, the display of cultural heritage in museums, whether it is a work of art, historical site or intangible cultural heritage (such as handicrafts) must consider the highlighting of its "authenticity". Authenticity includes the meaning of original, real, and trustworthy, and the original true state of cultural heritage should be preserved and displayed in museums as much as possible. "Authenticity" is the main reason why many people continue to be curious and concerned about cultural heritage, and also the primary purpose of visiting the museum. It is the authenticity that guarantees the museum's charm and its enduring possibility.

According to Benjamin "The Work of Art in the Age of Mechanical Reproduction" *:"even the most perfect reproduction of a work of art is lacking in one element: Its presence in time and space, its unique existence at the place where it happens to be. [...] Therefore, the original work of art is an objet d'art independent of the copy; yet, by changing the cultural context of where the art happens to be, the mechanical copy diminishes the aesthetic value of the original work of art. In that way, the aura — the unique aesthetic authority of a work of art — is absent from the mechanically produced copy."* He proposed that the original artwork has a particular worship value and can produce an "aura" effect. Among them, unique authenticity is one of the essential conditions for the "aura" effect, and mechanical reproduction eliminates authenticity and promotes artistic reproduction. Under this effect, the museum itself becomes a place to gather this "aura". Although in the age of mechanical reproduction, the "aura" brought about by the authenticity of the exhibits gradually dissipated.

The exhibits in museums based on "authenticity" originates from meeting people's deep-seated psychological needs. Human beings always have the curiosity to explore the original authenticity of things. They have to see them with their own eyes, and even want deeper interaction with exhibits personally. In the final analysis, humans have a lasting desire to experience the "authenticity" of things. With the popularization of communication media technologies, various museums and their exhibits have flooded the Internet world. Even if the materials and images are sufficiently clear and the shooting angles are sufficiently diverse (some museums even provide 360° panoramic views), people will still not give up visiting museums because of these "virtual" materials. A variety of materials are easily available in different media, but museums still attract many tourists every day. This is not only a herd motivation for visitors but also a cultural motivation and aesthetic motivation. The purpose of the exhibits in museums is to guide visitors' interest and understanding of culture and art. The museum space as a gathering place for "aura" often becomes a social place, which triggers cultural exchanges between different groups of people. This also makes it necessary for museums and their exhibits and display methods to be adjusted to meet the psychological needs of visitors in the overall context of the digital age. The rise of the internet and virtual vision technologies does not mean the elimination of traditional museum exhibition models, but more of the need to pay attention to the actual needs of visitors and the ways and means of communication and promotion. In the augmented exhibition which is the fusion of virtual elements and real space, the authenticity of the augmented exhibits has not disappeared in the intervention of art production through mechanical replication technology, but a new authenticity has been fabricated, and its worship value gradually replaced by representation value and experience value.

4.3.2.2 Authenticity in Architectural Space

The concept of authenticity was first applied in the field of culture, especially the discussion of authenticity in the field of art. The original work of art itself has a natural worship value which comes from the unique authenticity. The definition and scope of art are constantly changing. In fact, whether in ancient times or the Middle Ages, the scope of art is much broader than today's meaning. All technical products, skills themselves were called art, and art and craft were not stricven, even science was seen as one kind of art. It was not until the 19th century that craftsmanship and science were excluded from art, which narrowed the scope of art. Art and architecture in ancient times are a whole, and they are essentially interrelated. Architecture and art symbolize life, especially the mutual influence of architects and artists' thinking, philosophical trends, and artistic styles. The work of architects and artists sometimes merge with each other. Architecture and art have had a relationship since ancient times. There are countless examples of the fusion of architecture and art in history. Ancient Greek and Roman architecture is a fusion of architecture, sculpture and painting. Medieval church architecture provides space, place and inspiration for painting, sculpture and music, while medieval and Renaissance paintings often regard architecture as an ideal religious environment.

Therefore, architecture and art are always inseparable. In other words, architecture is also a great art and an indispensable visual art (Banham, 1960). This is the common recognition of many art historians, architectural theorists and architects. Architecture is also called "constructive art", "special art", "space and time art", "social art" and so on. Architecture is the art of society, urban spaces and places. Contemporary architecture is becoming more and more integrated with art, becoming an art of practical art and space practice. Architecture is especially seen as having the same structure as sculpture in some aspects. In the era of rapid development of contemporary internet, multimedia, and technology, fundamental changes are taking place in the way of art, art expression, and the way of disseminating art and experiencing art. In this respect, contemporary architecture is more representative than other arts. Architecture sometimes leads the era, and its avant-garde even surpasses many other artistic fields.

Fig.4.9: Tourists are taking photos with the Sydney Opera House

In fact, when architectural space exists as art, it has "aura", that is, it has the authenticity of artistic aesthetics. This authenticity can be understood as a representation authenticity. This authenticity is usually presented to users from the appearance of the building, just as the various landmark buildings that have emerged in recent years have become a city's business card or tourist attractions. We can see many tourists posting photos of themselves and the “net celebrity” buildings on social media (Fig.4.9). From the point of view of tourists, these buildings, especially contemporary buildings and other cultural heritage, together form a symbol of the city, and this is also an affirmation and promotion of architecture as art. From the perspective of authenticity, the architectural space itself has the same representation value as an artwork.

IIn addition to this, architectural space can also provide another kind of authenticity, namely experience-driven authenticity. Architecture is different from paintings and sculptures and other artworks in that it has not only representation value but also use-value. Moreover, its use-value is even higher than the aesthetic representation value. This shows that the architectural space itself also has the experience value of providing services. This can be attributed to the connection between social activities and cultural identity in a certain geographic area, that is, the "terroir"

(Zukin, 2010) of the architectural space. "Terroir" puts more emphasis on the chemical reactions that occur under the combined effect of architectural space, cultural identity, and social activities at specific times and occasions. Although the architectural space itself does not have the unique right to belong to a certain group of people, the different experiences it inspires are unique. This means that authenticity in architectural space is not only a visual image; it is actually a series of social activities and experiences reflected by the designed environment. The experience authenticity of architectural space is not only the physical structure of the building, but the key lies in the real experience and activities in the space.

As a result of careful design by architects, the architectural space has the representation authenticity equivalent to the value of artwork. Its use-value in turn triggers the experience authenticity conceived by users in the using of architectural space, social activities and cultural exchanges. This "aura" of experience authenticity seems to be unable to be dispelled by the so-called mechanical reproduction. Videos and pictures cannot restore the sense of presence and immersion brought by the real architectural space. Therefore, users must go to the field to experience the authenticity of the architectural space. However, virtual vision technology seems to challenge the authenticity of experience visually, though we know that vision is not the only unshakable foundation of authenticity. If virtual technologies can bring more sensory simulations and integrate more realistic social attributes in next years, then we may have a new question: Will the authenticity of experience be continuously eliminated by new technologies in the future?

4.3.2.3 Authenticity in Virtual Experience

Before solving the problem mentioned above of authenticity being resolved, we do not need to worry too much, because the concept and meaning of authenticity are also constantly improving with the development of the times and technology. Every technological innovation and production mode change in society will bring about changes in people's art and culture concepts. Benjamin's theory reflects the transformation and promotion of mechanical reproduction technology from worship value to representation value. Today, when consumerism is prevalent, the concept of authenticity plays an essential academic significance in the fields of culture and consumption. Many scholars have begun to use the concept of authenticity to study cultural, economic phenomena and try to use cultural industries to solve economic problems. In different cultural contexts and research backgrounds, whether authenticity is absolutely true or not has begun to be questioned. The concept of "Fabricating Authenticity" (Peterson, 2013) believes that authenticity is often not derived from facts or nature in the cultural industry, but can be created by companies. Hansen and Mossberg also believe that consumers will not deliberately pay attention to whether the product culture is artificially fabricated, but are more inclined to find credible and unique cultural elements in an immersive experience[1]. It can be seen that authenticity can be created artificially and accepted and recognized by consumers. With the rapid development of virtual vision today, the authenticity of augmented exhibits and virtual experiences can be redefined and applied to museums and cultural activities. The virtual environment's authenticity has not disappeared, but the new experience value has been produced based on the integration of creativity and space. The value of the virtual experience can be

1.Hansen, A. H., & Mossberg, L. (2013). Consumer immersion: A key to extraordinary experiences. In Handbook on the experience economy. Edward Elgar Publishing.

summarized in two aspects: creative value and place value.

The creation of virtual environments is inseparable from the creativity and inspiration of designers and architects. Although some virtual environments are recreated based on existing real spaces, the creation process still requires the participation of architectural design methods. The interaction, behaviour and experience of users in this virtual environment can be summarized as "virtual experience". The first thing the virtual experience gives users is the visual level. This vision can be based on the real world or use the designer's ingenuity to create a new aesthetic space art. In the virtual experience of users or consumers, they want to see the scene reproduction that can be observed in the real world and hopes to complete some behaviours and activities that are difficult to complete in the real space through the virtual experience. The virtual experience's creative value is to build a bridge between the modern and digital new lifestyle and the existing culture and real space through augmented space design. Virtual experience meets the needs of contemporary users, attracts experiencers to the place where the virtual environment is created, and then realizes a new dialogue between the user and the original space in the form of renovation, activation and re-creation.

Place value is another crucial parameter in the virtual experience. The virtual experience is not just the so-called virtual reality; it can also be said that virtual reality is just an extreme expression in the virtual experience. The virtual reality that is separated from the real space and the experience environment does not have the value of the place, and it also loses the authenticity behind the place value. Place value can be understood as the background of creative output in the virtual experience. This background is not just a background layer from a technical perspective or a background scene that provides AR effects. It is more about the cultural heritage attributes of the space itself and the personal experience that space itself brings to users. In a deeper context, the "background" of the value of the place itself has the authenticity of the architectural space. The augmented space based on this "background" and virtual experience refer to the authenticity of the original space and amplify this authenticity. Place value must be referenced and studied in the design process of the virtual environment and experience. Only by carrying forward the place value and cultural value in the original space as much as possible can the virtual elements be integrated into the place in a better way. This contrast and immersion between virtual and reality will bring a new experience in the digital age.

Based on the authentic architectural space, and inspired by virtual elements created by digital technology, the real space and the virtual environment are closely and creatively integrated so that a new chemical reaction occurs. The augmented space created by combining a cultural background and scene interaction is the charm and value of virtual experience authenticity.

4.3.3 Virtuality and Fear

The birth of new technologies is generally accompanied by doubts and even fears of technological revolution. At the beginning of the birth of photography technology, it was once called a "capturing soul machine", and now cameras are almost everywhere in the world. The popularity and development of AR and VR is not a simple, predictable upgrade in graphics (compared to sharper picture quality and faster response times). The disruptive nature of the experience and perception can leave it in a "camera" dilemma. With the development of technology, virtual elements will become more real, and the improvement of its simulation will also bring about the "uncanny valley" effect, The concept was identified by the robotics professor Masahiro Mori: *"In aesthetics, the uncanny valley is a hypothesized relationship between the degree of an object's resemblance to a human being and the emotional response to such an object. The concept of the uncanny valley suggests that humanoid objects which imperfectly resemble actual human beings provoke uncanny or strangely familiar feelings of eeriness and revulsion in observers. "Valley" denotes a dip in the human observer's affinity for the replica, a relation that otherwise increases with the replica's human likeness"*

Facing the technological development of increasingly high-precision display devices and potential multi-sensory experiences, it is foreseeable that virtual vision technologies such as augmented reality will cooperate with more technical means to bring users a more immersive experience. The "uncanny valley" effect means that virtual experience designers cannot simply assume that more senses are better, or that more realism is better. Virtual elements will produce conflicting perceptions of multiple sensory channels. When the human brain subconsciously integrates these conflicting cues into a unified perception, the final result may reduce the subjective experience, reducing immersion. This also shows that we need to shift the focus of virtual environment design from precision (fidelity) to creativity and the connection with the real environment, and we need more related disciplines such as architecture, urban science, and consumer psychology to create and integrate design an augmented space that meets the needs of contemporary user experience.

4.4 The Significance of Museums in Digital Space

Museums in the digital and internet age are facing many problems. From the perspective of the museum's own management, museums lack the ability to operate in the market in the Internet era. Although the government will bear part of the economic pressure of the museum, subsidies are indeed minimal for the operation of the museum. If we do not think about the new path of reform and development in the modern era, it will lead to a continuous decline in the exhibition quality of the museum's carrying capacity, which will lead to a further decrease in the number of visitors, forming a vicious circle. In terms of external influences, the trend of shared culture means that museums are gradually losing their "inherent territory." For visitors, the unique cultural value of museums is slowly weakening. Museums are not only facing the rapid expansion of the number of internal industries. Competition is, even more, a struggle for visitors' attention with diverse cultural and art organizations.

In the digital and post-Covid era, people have more and more channels to obtain information. Even at home, they can enjoy various artworks through the Internet and VR glasses. The situation faced by the museum's physical space compels it to develop its own value of place experience. Although the "aura" of authenticity of artworks is diminishing in the museum space, the experiential authenticity of the space itself and its digital enhancement will complement and upgrade the original meaning of authenticity. The "aura" created by the new virtual art and the real place together will continue to attract visitors to the museum as a "sacred" space to experience the unique cultural charm. At the same time, Museums have to meet increasingly scarce financial support and increasingly brutal market competition. The museum's development strategy has changed from focusing on exhibits to concentrate on the visitor experience. Building a museum brand, actively participating in market competition, and developing new exhibition models has become an effective and sustainable development strategy.

In the process of museum transformation and development, the key to reversing the vicious circle is to attract the attention of visitors. The development of Internet technology requires modern museums to have a scientific positioning of the needs of society and the museum itself, and establish the user experience as the core strategic goals. Compared with other cultural institutions, museums have rich cultural heritage resources. Therefore, authenticity has become the essential value of museums. Paying attention to the authenticity of the exhibition experience has become the primary means for museums to achieve differentiation and participate in market competition. Carefully weigh the advantages and disadvantages of museums, fully consider the demands of designers and visitors, correctly treat the relationship among visitors, exhibits and space, and adopt appropriate methods to play the role of creative and experience authenticity will be the right direction for future museums to respond to the rise of digital space. Augmented architectural space based on digital elements does not mean the demise of physical buildings; on the contrary, it can bring new spatial forms and experiences to traditional museum spaces.

4.5 Short List of Bibliography

1. Aurigi, Alessandro, and Fiorella De Cindio, eds. *Augmented urban spaces: articulating the physical and electronic city.* Ashgate Publishing, Ltd., 2008.
2. Benjamin, Walter. *The work of art in the age of mechanical reproduction*. Penguin UK, 2008.
3. Berger, John. *Ways of seeing.* Penguin uK, 2008.
4. Ettlinger, Or. "In Search of Architecture in Virtual Space." S*lovenia: University of Ljubljana (2008)*: 64.
5. Mitchell, William John. *City of bits: space, place, and the infobahn.* MIT press, 1996.
6. Pine, B.Joseph, and James H.Gilmore. *The experience economy*. Harvard Business Press, 2011.
7. Ratti, Carlo, and Matthew Claudel. *The city of tomorrow: Sensors, networks, hackers, and the future of urban life.* Yale University Press, 2016.
8. Solko, David. *Evaluating Enhanced Reality Interfaces and the Museum Experience.* Diss. University of Cincinnati, 2018.
9. Tatarkiewicz, Władysław. *A history of six ideas: An essay in aesthetics*. Vol. 5. Springer Science & Business Media, 2012.64.
10. Zukin, Sharon. *Naked city: The death and life of authentic urban places.* Oxford University Press, 2009.

CHAPTER 5

CASE STUDY BOOK

5.1 Criterion

5.1.1 Introduction

Augmented Reality (AR) and Virtual Reality (VR), as new tools for new media and architectural representation, the combination with museums means an innovative and challenging attempt. AR and VR technologies use dynamic and visual virtual elements to achieve interaction with the real environment, giving people a sense of immersion, which can arouse the audience's participation and enthusiasm. It helps architects and designers to provide a new approach of interpreting spatial language, that is, an augmented space formed by digital elements and noumenal space, which concerns an experimental new subject for both museum space and new technical media. The change of space and media representations brings many novel elements, including the transformation of the space itself and the definition of visitors' behaviour and interaction in exhibition spaces.

As an important research method, case studies have positive significance for analyzing museum spaces' changes and influences under virtual visual technology. This chapter will collect some excellent examples of using virtual vision technology in museums or exhibition spaces worldwide, including various types of museums. Analyze these cases, try to interpret why and how designers and curators think about using these visual technologies in the museum space, and explain the difference between the original space and the spatial form under the influence of these virtual technologies from the perspective of space and user experience.

If the significance of case analysis is only to tell the story, that is, the state of the exhibition space and the augmented space in a given environment are far from enough. Based on respecting existing data, following the logic system of architecture and interactive cognition brought by new technological innovation, and producing advanced knowledge is the principal significance of case studies. Specifically, it is through a series of case selection and research to try to understand the background and inspiration behind the story itself, to show the causal mechanism and process of its design; to understand the systematic and relevant characteristics of this knowledge, so that the case analysis has relevance and comparison relationship; to explore the enlightening significance of new technologies for future exhibition spaces.

5.1.2 Selection of Cases

With the maturity and popularization of AR and VR technologies, more and more exhibition spaces in museums have begun to use virtual visual technology to create a new experience mode for visitors. These projects attempt to introduce a new exhibit type, that is augmented exhibit. Unlike the virtual exhibit (such as digital elements on-screen or projection), the augmented exhibit is more tightly integrated with the physical space, which is more in line with the interaction logic between visitors and real exhibits. Virtual exhibits promoted the formation of augmented space in museums which are the research subjects in this chapter. According to the proportion of virtual elements in real space, the exhibition space's augmented level can be divided into four levels: low, medium, high and full virtual(VR). Facing many museum cases in the digital age, choosing suitable projects as research targets from a large number of augmented space cases becomes a critical decision. Based on the process of architectural and interior design, the original essence of exhibition space in the museums, and user experience through virtual vision technologies, the selection and classification of cases will be according to the following four criteria:

1. Inspiration

Excellent museum exhibition cases contain the creativity and inspiration of architects and designers, and praiseworthy inspiration and creativity are often the keys to a design project's success. Inspiration is a very abstract and unique attribute that is not easily quantified, and it is also the embodiment of the core creativity and value of architects and designers. Compared with large-scale planning and architecture projects, small interior public spaces like museum exhibition spaces, designers have more voice and leading ability. This also means that architects and designers' inspiration mainly drives the completion of an exhibition space that amazes visitors in the museum. Because of the augmented space in the digital age, inspiration and creativity are more prominent. Augmented reality gives designers more possibilities, whether it is a simulated virtual object based on a real physical environment or an impossible space beyond physical limitations. The exponential increase in possibility seems to provide more background and support for creating architecture in the museum exhibition space. In fact, for architects and designers, the challenges and choices they face are unprecedented. The interpretation of inspiration can help architects to explain better this conceptual and elusive design tool in the design process. Where these inspirations come from, and what changes have taken place in realising these ideas, are the essential points to be studied in the research. Because of this, inspiration is one of the essential criteria for case selection in this chapter.

2. Space

The essence of architecture is the study of space. How the appearance of virtual objects will affect physical space is the focus of this part. Virtual objects' effect on space is evident, whether the virtual objects created by AR enrich the content of real space or use VR to create a completely independent virtual space. The spatial form and architectural vocabulary will renew itself under the action of virtual elements. This renewal will start from the museum and gradually penetrate various types of architectural spaces around us. Under the influence of this virtual technology, our spatial form can produce many variations: With virtual technology, we can place virtual objects in space like furniture, and we can create objects that divide the space between making the space more versatile; At the same time, we can also simulate different material effects, so that the experience of the space produces abundant changes; even we can create an optical experience through virtual objects. In the museum space, the influence of virtual elements on the space is obvious. Ingenious borrowing of virtual elements and augmented interaction can evolve the exhibition space into a distinctive augmented space. As criteria of cases selection, this part of the case study explains how virtual exhibits and augmented space affect the original space.

3. Technology

Technological progress is the basis for the formation of new spaces. Just as electronic lighting technology has changed the lighting form of traditional buildings, virtual visual technology is changing the space of museums. The primary technical principles of AR and VR have been clarified in the previous section. The choice of cases based on technologies is not only VR headsets and smartphone applications familiar to users, but also some innovative attempts in virtual vision technology. This kind of innovation is not necessarily a revolutionary technological innovation, it is likely to be an improvement in certain details of technology or experience. At the same time, virtual exhibits and space will also have corresponding changes. Technology and interactive experiences have evolved into architectural elements such as concrete and bricks. Architecture as a solid artwork, traditional space will expand its spatial form with a more dynamic and changing attitude with the support of new media. There is no doubt that technology has become a part of the architecture. Designers are taking on more and more roles in museum exhibition space. Programmers, choreographers, and engineers will be the work and responsibility of the designers in the future exhibition space. Even in some cases, we found that the core creative team is not an architect in the traditional sense. The more leading role is the technical staff in the team, especially the designers engaged in CG (Computer Graphics). This also seems to indicate that technology is no longer just a basic and support subjects behind the architectural space in museum, but has gradually become one of the influential criterion affecting the final effect of the exhibition space.

4. User Experience

User experience is the attitude, feeling and feedback of users themselves when using products or services. In the museum, user experience can be understood as the visitors' behaviours and psychological feelings during the exhibition. Visitors as users of museum space types, The feeling of space and the experience of viewing the exhibition are crucial. For modern digital products, user experience is one of the core parameters that need to be considered and designed throughout the development process. The augmented exhibition space formed under the support of virtual vision technology can be seen as a new combination of architecture and digital application. Therefore, user experience cannot be ignored in augmented exhibition space in museum design; This part will select cases that greatly enhance user experience through AR and VR technologies. Although technically it is maybe just using the most basic AR or VR technology. Experience design is one of the most critical factors in digital product and the process of creating these augmented spaces. Designers use a combination of the essential elements to create costly spatial types that give users an augmented experience due to the presence of augmented spaces. The intervention of virtual objects and space enhancement provide the exhibition space with a new experience, which is often interactive. Unlike traditional spaces, interactive spaces bring instant feedback. Users can participate in the process of changing the space, although this change may be based on virtual exhibits. As Tali Krakowsky said, *"New media and technologies are providing a glimpse of what interactive architecture can be. Now we must build it."* [1]

1. https://segd.org/interactive-architecture

5.1.3 The Structure of Cases Study Book

The case studies in this chapter are developed through a set of themed parts including "introduction", "concept", "analysis" and "feedback".

The first part "introduction" will explain some basic information about the case, such as museum location information, design team and start time of augmented exhibition space, tour equipment, techology type etc.. In the second part "concpet", the essay will focus how the design inspiration was born, how to establish a strategy to realize the initial concept through the project and sort out the complex relationship network in the design process among the designer, curator, museum and visitors. The third part "analysis" will explain which and how technology this case uses in the exhibition space, and try to interpret the changes in space under the influence of new technologies from traditional architectural analysis methods. Changes in user experience are also what needs to be discussed in this section. In the final part "feedback", will collect reports and evaluations of the project by magazines, newspapers and Internet media. Vistors' thoughts and feedback on the case are also important for this research based on digital ethnography. Each case analysis will follow the above-mentioned structural framework, and carry out corresponding extended analysis and interpretation according to the characteristics of the case itself.

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5.2 Cases Study

Case No.	Project	Museum	Location	Year	Design Team	Tech.
1	*ArtLens*	Cleveland Museum of Art	Cleveland, USA	2013	Local Projects	
2	*Hacking the Heist*	Isabella Stewart Gardner Museum	Boston, USA	2018	Cuseum	
3	*Air, Land&Sea*	Putnam Museum	Davenport, USA	2017	INDE	
4	*Step Back in Time*	Singapore National Museum	Singapore City	2017	GuidiGo	
5	*Invasive Speices*	Pérez Art Museum Miami	Miami, USA	2017	Felice Grodin	
6	*Smart Guide in Casa Batlló Museum*	Casa Batlló Museum	Barcelone, Spain	2015	Universitat de València	
7	*Rhomaleosaurus: Back to Life in Virtual Reality*	The Nature History Musem	London, UK	2016	Framestore	

Legend

Smart Phone

Headset

Tablet

Augmented Reality

Projection Screen

VR Controller

Fig.5.1: “ArtLens App” Experience in Cleveland Museum of Art, 2013
Source: https://mw2014.museumsandtheweb.com/bow/artlens/

Case1: ArtLens

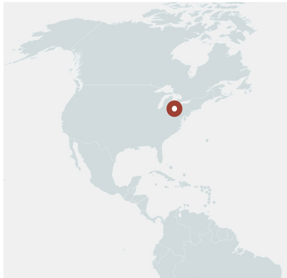


Fig.5.2: Cleveland Museum of Art Position

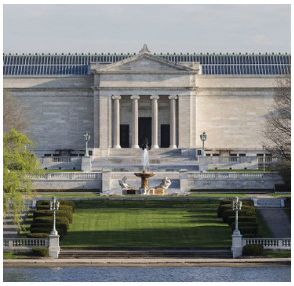


Fig.5.3: Cleveland Museum of Art Photo

Cleveland Museum of Art

Design Team: Local Projects
Cleveland, USA
2013

Museum Type: Art Museum
Tech. Type: Augmented Reality + Interactive
Tech. Devices: SmartPhone and Tablet
Tech. Support: Local Projects

Introduction

Cleveland Museum of Art(CMA) is an art museum located in Cleveland, USA. The museum has collected more than 60,000 works of art from all over the world. It contains a large collection of world-renowned Asian and Egyptian art and cultural relics. Approximately 770,000 tourists from all over the world visit here every year, which proves the collection and charm of the museum. Since 2005, the Cleveland Museum of Art has been expanding and renovating for 8 years. The renovation project has expanded the museum area by about 60% to 55,000 square meters.

The ArtLens project is a series of interactive devices (such as large touch screen, motion capture system, etc.) and smart phone application contains all navigation information, interactive digitized collection, and AR program that can display information about

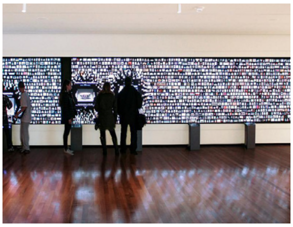


Fig.5.4: A forty-foot touchscreen visualizing all 4,000 works

artworks. Important items in the series include a 40-foot touch screen (Fig.5.4), which displays a large number of pictures of art works. Visitors can quickly browse the exhibits and collections they expect to watch by touching the screen, and the smart program will plan the best tour route. And another important part of the series is also the focus of this case study is the combination of augmented reality and artwork. Mobile phone application can not only provide basic functions including real-time navigation and information retrieval, but also can demonstrate detailed interpretations of art works on the phone screen through AR technology.

This project is designed and developed by CMA and Local Projects. Local Projects is an experience design studio in New York and the studio hope to connectpeople to brands and cultural institutions through meaningful interactions. For some of their

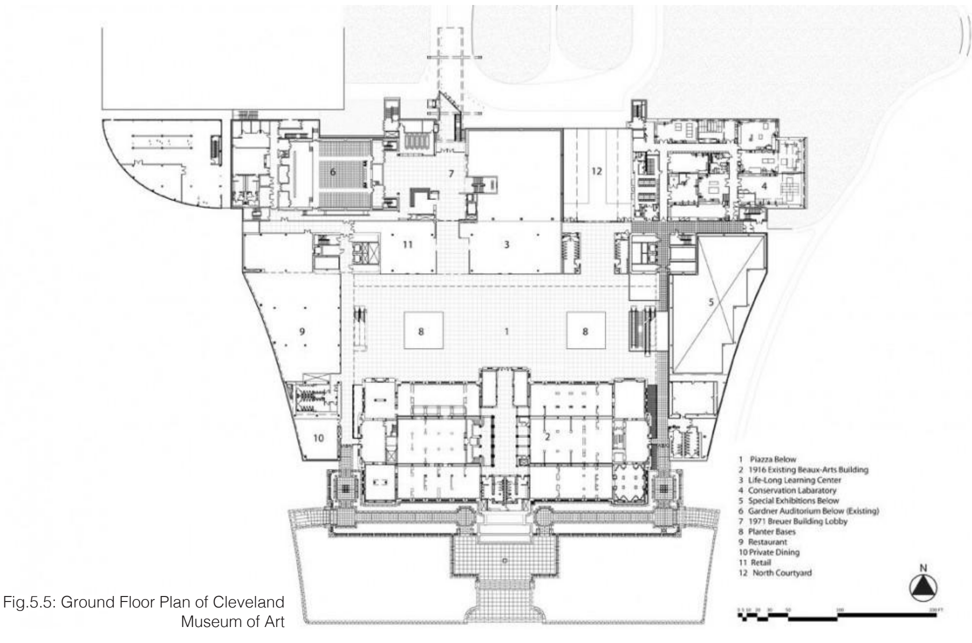


Fig.5.5: Ground Floor Plan of Cleveland Museum of Art

outstanding projects, The studio would take a chance on immersive and innovative approaches that can inspire emotion and create strong memories. The potent combination of creative technology and physical design is their pursuit of project quality. Their success stories include *A Museum of Collective Memory (National September 11 Memorial & Museum)*, *Hyde Park Barracks Museum (Sydney Living Museum)* and so on.

Concept

- Inspiration:

The development of new technology has brought a profound impact on the display method and experience process. In order to cope with this development and change, Cleveland Museum of Art decided to respond to this challenge through new technology and new media. The museum wants visitors to interact with the basic principles of creating art and have a new understanding of their own subjectivity. We hope that artworks are not in front of digital art, but to create numbers in front of digital art. The museum hopes to explore the digital representation of artworks through a simple operation process, so as to have a deeper appreciation of the real physical artworks in the museum. Because of this, Cleveland Museum of Art cooperated with the Local Projects to develop ARTLENS Exhibition, ARTLENS Exhibition at Cleveland Museum of Art allows visitors to digitally interact with art as never before, dive deeper and get a closer look to the artwork seen throughout the museum. Google once wanted to use the Google Art Project to digitize the museum's art collection and publish it on the Internet. The museum director David Franklin rejected them because it was not because they rejected technology. The real reason is *"Only at a museum can people truly engage with art. The experience of standing in front of* *a sculpture or mosaic or tapestry or painting can never be replaced by a digital image on a computer screen. No matter how many museums Google Art maps, art viewed on a screen is, quite literally, an experience without true depth."*[1]

1.Of Pixels and Paintings: Gallery One, ArtLens and the Role of Technology in Museums, https://www.huffpost.com/entry/cleveland-museum-of-art

- Strategy:

The museum decided to use Gallery One as a place for experimental technology and art, that is, ARTLens Exhibition. Gallery One is a unique interactive space that is both a breathtaking artistic experience on its own terms and a groundbreaking technological portal to our collection. ARTLens is A systematic exhibition experience composed of multiple technologies and multimedia types, including a 40-foot long Collection Wall. The wall, the largest multi-touch microtile screen in the United States, displays nearly 4,000 objects from the Museum's collection-that is, every object on view in the museum. The focus of this case analysis is another important part of ARTLens, AR Application. The museum found in the preliminary research that visitors spend very little time in front of the artwork , The median is around 17 seconds (less than 10 seconds to read the text description), which means that the traditional interaction between visitors and exhibits is passive and negative. The museum and Local Projects hope to solve this problem through digital methods and Application. ArtLens can track visitor's location anywhere in the museum and tell visitor what you are viewing. Museum visitors can choose to increase or decrease additional content according to their wishes. When the visitor points to the artwork on the wall with the application, the description and interpretation of the artwork will be displayed on the screen through real-time interaction. This is not just a simple copy of the text description of the artwork, but is aimed at Different artworks have been customized in detail. For example, in the example of Fig.5.6, visitors can see detailed instructions whichcorrespond to different parts of the painting on the screen. As Frankin said: *"As a museum director, one of the elements of this technology that has me so excited is that it allows me to ultimately consider removing text and explanations from the walls of the museum, while providing much more information to museum goers who seek it out. The iPad is the new text panel, which means the art can speak for itself."*[1]

1.Of Pixels and Paintings: Gallery One, ArtLens and the Role of Technology in Museums, https://www.huffpost.com/entry/cleveland-museum-of-art

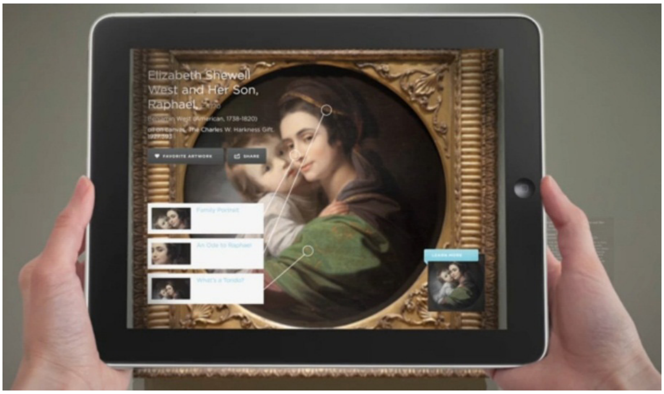


Fig.5.6: Instructions on the iPad screen through Augmented Reality
Source: https://accuware.com/blog/location-awareness-in-museums/

- Project:

The overall ARTLens is a large-scale digital and museum physical space project, and AR technology is only one of the applications. Specific to this case, the principle of technical realization seems very simple, but the actual preparation work is very much. As mentioned above, the interpretation of art paintings is not a simple description, but needs to be accurate to the specific parts of each painting, which means that high-precision control of the target object needs to be maintained during the AR preset process. Furthermore, these AR projects also need to be integrated and compiled with other ARTLens projects as a whole, which makes the implementation and completion of the project difficult.

- Relationship:

The project is led by the museum, and the concept and idea of the scheme is proposed by the museum. Under the new technological revolution, the museum first established the relationship between technology, artwork and visitors, and closely linked this interactive relationship with the museum space. This means that visitors' experience of the art begins with the art on its own terms. Then, inspired by the emotional experience, they can use ArtLens to have the intellectual experience of learning about the piece, its origins, its creator, and its context. Museums should resist techniques that flatten and trivialize interaction. On the contrary, this kind of technology that can promote, deepen and expand interaction is worth encouraging. It is worth mentioning that in the process of fusion of processing technology and art museum space, a premise is always maintained: the authenticity of the museum space and artwork is the most important. This respect for space and art is worthy of encouragement. Visitors play the role of bridge and

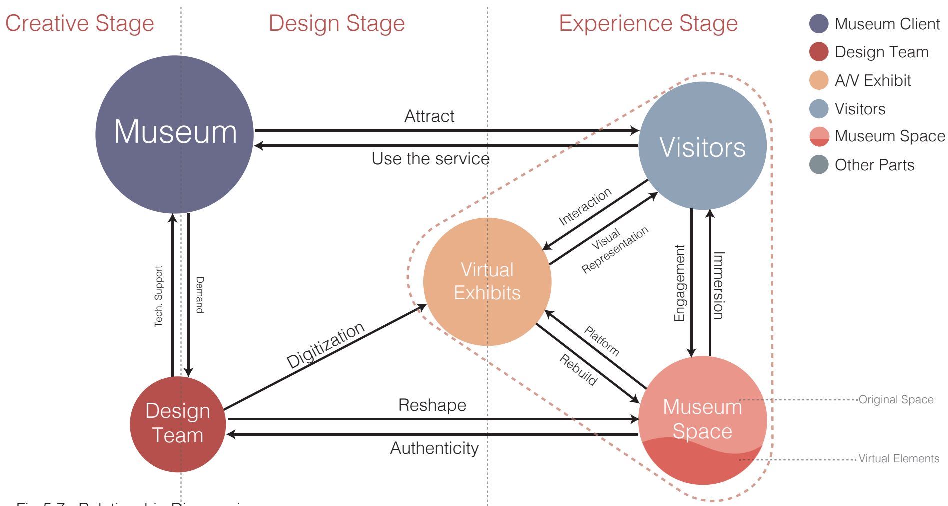


Fig.5.7: Relationship Diagram in "Invasive Species"
Source: Made by Author

link in the museum space. With the help of technology, they can participate more in the space and have a deeper dialogue and experience with artworks. This experience is not completely virtual, but is enhanced on the basis of real spaces and artworks.

Analysis

- Space:

From the experience of architectural space, the ARTLens project has not made substantial changes to the building in space, but the behavior of visitors in the space has undergone many changes, and visitors are more willing to stay in the space and interact with the exhibits. The traffic space in the past has now become a stay space, and the exhibition hall has also added interactive space. Normally, the paintings of art museums are hung on the walls, and the area where visitors enjoy the paintings is generally closer to the paintings. The changes in interaction methods brought about by new technologies have also changed the perception and function of space (as shown in Fig.5.8). Another interesting change is that the

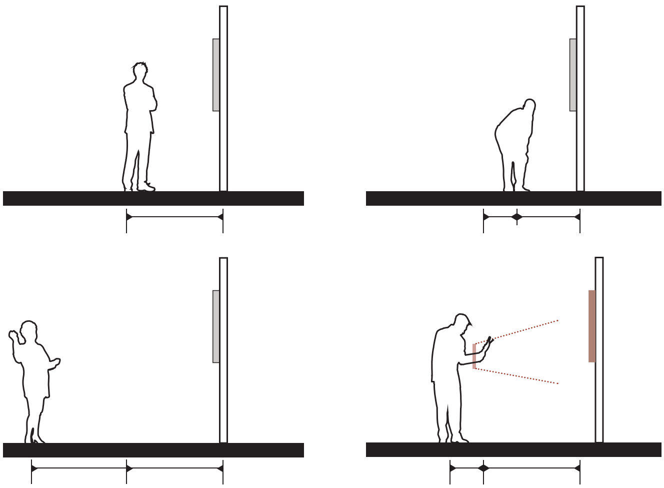


Fig.5.8: Diagram: Different distance in visiting artwork with and without handheld device
Source: Made by Author

museum removed the interpretation of the paintings from the walls and displayed them entirely in the form of application.

- Technology:
This project uses an AR application in a typical object replacement mode. The target object is captured by the camera of the iPad, and the preset interpretation information is overlayed on the screen in the form of AR through program calculation. This experience is not limited to the right painting. As long as the viewing angle is within a certain range, the painting can be correctly identified, and the floating information will be changed according to the user's perspective changes. In addition to the AR system, Application also integrates many practical functions, such as navigation in the museum and retrieval of exhibits. Visitors

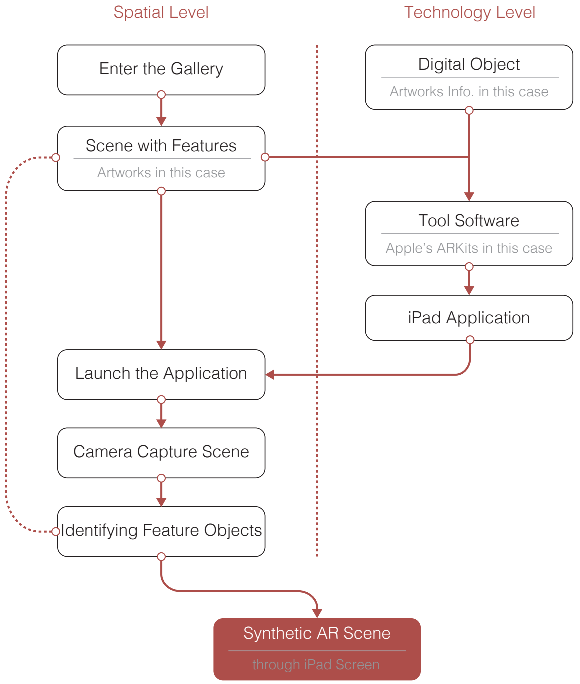
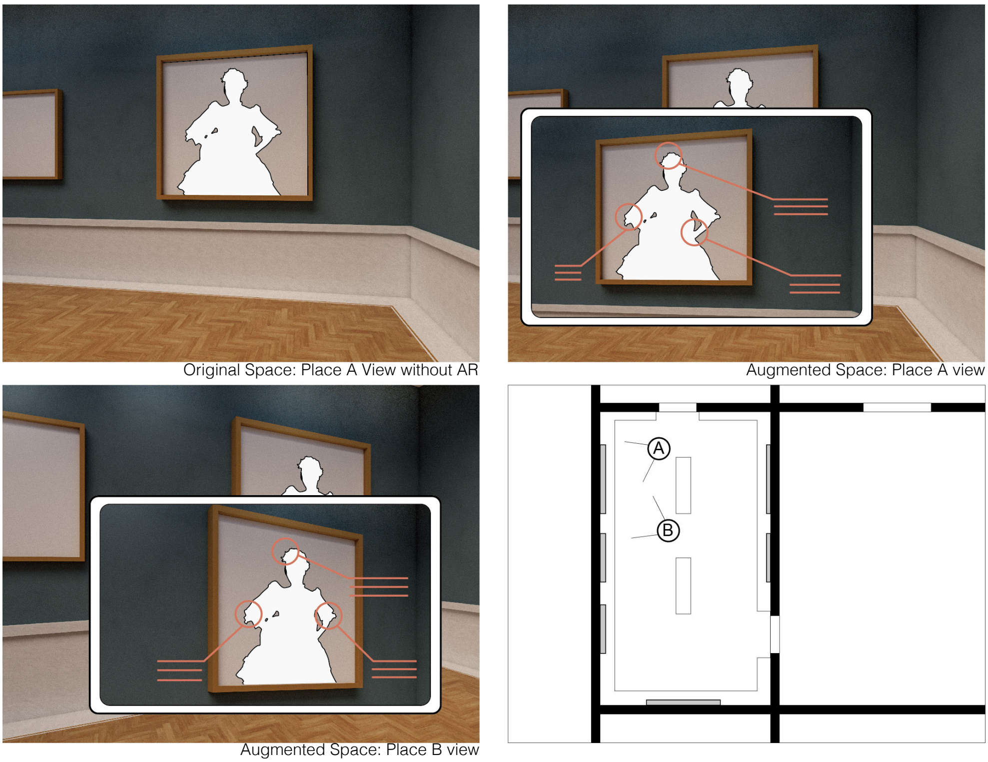


Fig.5.9: Spatial level and tech. level work flow in this case
Source: Made by Author

can customize their tour routes according to their preferences. The design of the App itself is also worth mentioning. The fluency and experience have been carefully polished, which also lowers the threshold for users to use new technologies.

- Experience:

The visitor's experience is interesting and varied during the exhibition. Application can be customized with a high degree of freedom, allowing visitors to explore the museum according to their interests or preferences. The sorting and customization of information helps visitors to interact with the art museum in a more



Original Space: Place A View without AR

Augmented Space: Place A view

Augmented Space: Place B view

Fig.5.10: Original space and augmented space in different views
Source: Made by Author

targeted manner. These interactions using new technologies are not a gimmick, but actually help visitors to better integrate into the authentic experience of the art museum. Technology and fun can give visitors a deeper understanding of the artwork, the author and background knowledge behind it, and the time that visitors stay in front of the artwork is the best proof. Another benefit of this kind of interaction and fun is that it reduces the fatigue caused by museum visits. The intertwining of multiple interactive methods also avoids the sense of repetition in the experience, which helps visitors participate to different exhibition projects in the museum space.

Feedback

Once the ARTLens project opened to the public, it attracted the attention of many people. As an advanced interactive experience project, the integration of technology, space and art did not cause contradictions and conflicts among the three, indicating that the project itself was successful. The project has also won many technology and art-related awards, such as: Communication Arts Awards (Award of Excellence), Edison Awards (Gold) and Communicating the Arts Grands Prix Awards (Gold). In addition to the praise given by the media and experts, more important feedbacks come from visitors. According to the museum's survey of visitors (as shown in the Fig.5.11), there is a clear majority of people who have a positive attitude towards this enhanced exhibition. But there are still many people who are skeptical and rejecting this new technology. One potential reason is age, young people are more accepting of new technologies. For older user groups, they may need some time to learn how to interact with digital devices, and once they learn how to use these, they will also be interested in these new exhibition modes and begin to immerse

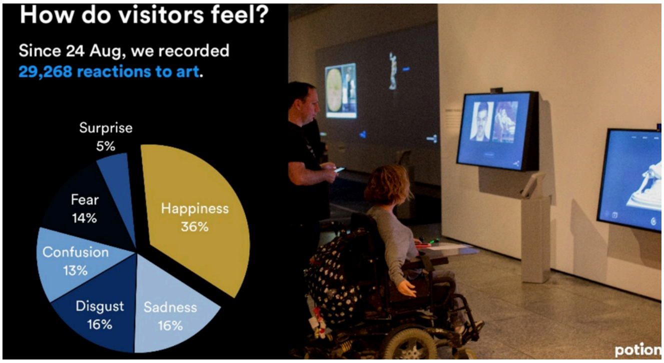


Fig.5.11: Visitors' Feedback survey
Source: https://www.slideshare.net/PhillipTiongson/artlens-gallery-designing-meaningful-barrierfree-digital-experiences-82172309

themselves in new experience brought by the new digital technologies.

References

1. Pollalis, C., Gilvin, A., Westendorf, L., Futami, L., Virgilio, B., Hsiao, D., & Shaer, O. (2018, May). ARtLens: enhancing museum visitors' engagement with african art. In Proceedings of the 2018 ACM Conference Companion Publication on Designing Interactive Systems (pp. 195-200).

2. Museum Offical Site, Accessed August 25, 2020,https://www.clevelandart.org/artlens-gallery

3. Please Touch the Art, Accessed August 25, 2020, https://www.localprojects.com/work/interactive-installations/please-touch-the-art/

4. Reframing Art, Accessed August 25, 2020, https://www.potiondesign.com/project/artlens-exhibition/

5. Technology That Serves to Enhance, Not Distract, New York Times Accessed August 25, 2020, https://www.nytimes.com/2013/03/21/arts/artsspecial/at-cleveland-museum-of-art-the-ipad-enhances.html?pagewanted=all&_r=0&mtrref=undefined&gwh=0650EBE5BAC3C1F945D116E39D85B50F&gwt=pay

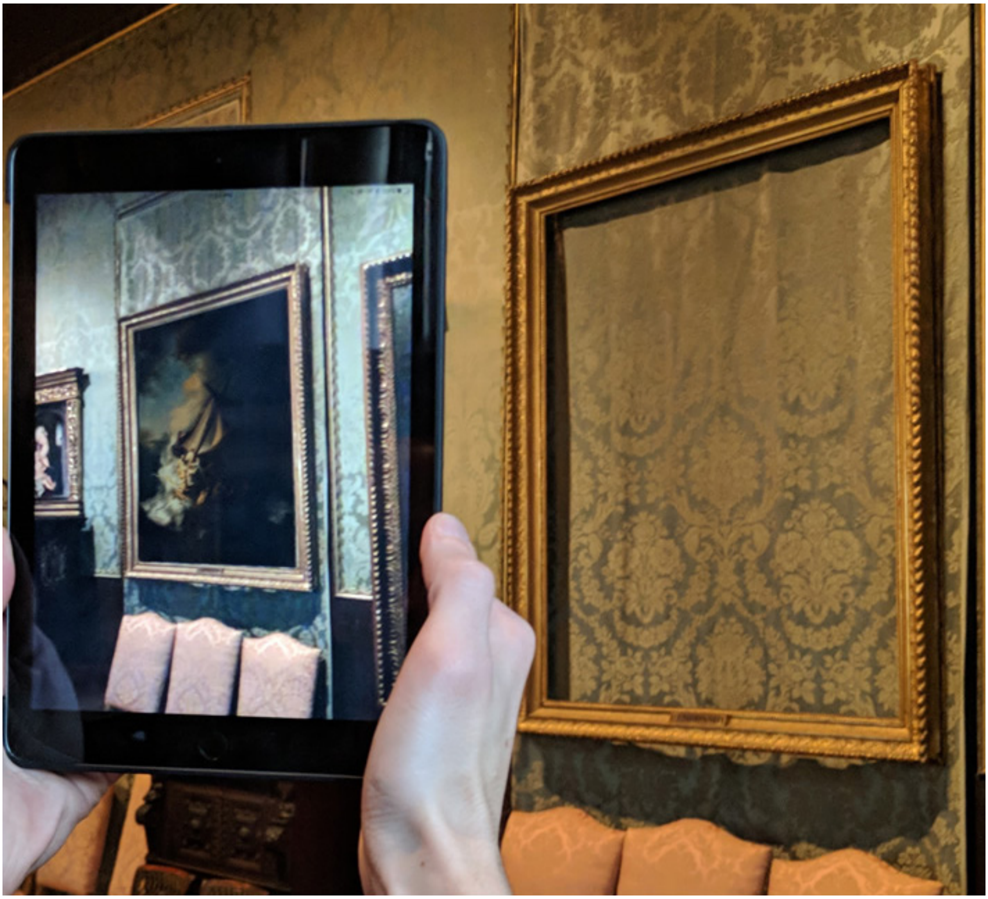


Fig.5.12: “Hacking the Heist” Experience by iPad, 2018, Isabella Stewart Gardner Museum,Boston, USA

Case2: Hacking the Heist

Isabella Stewart Gardner Museum

Design Team: CUSEUM
Boston, USA
2018

Museum Type: Art Museum
Tech. Type: Augmented Reality
Tech. Devices: iPad
Tech. Support: ARkit
Agency: Isabella Gardner Museum

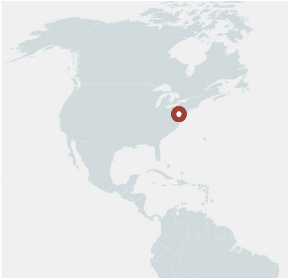


Fig.5.13: Isabella Stewart Gardner Museum Position

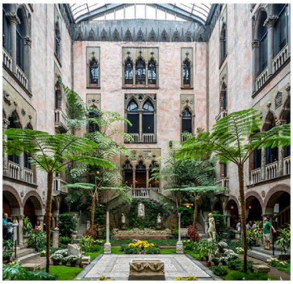


Fig.5.14: Photo of courtyard, Isabella Stewart Gardner Museum.

Introduction

"Hacking the heist" is a project which is leveraging AR technology placed the stolen art work pieces back in their original frames in Isabella Stewart Gardner Museum. The Isabella Stewart Gardner Museum is an art museum in Boston, Massachusetts, which houses significant examples of European, Asian, and American art. Its collection includes paintings, sculpture, tapestries, and decorative arts. It is originally the home of Isabella Stewart Gardner, whose will called for her art collection be permanently exhibited "for the education and enjoyment of the public forever"[1]. Unfortunately, on March 18th, 1990, thieves broke into the Isabella Stewart Gardner Museum and stole a total of 13 works of precious art masterpieces worth more than $500 million. In 2018, the museum collaborated

1. https://en.wikipedia.org/wiki/Isabella_Stewart_Gardner_Museum

with the Cuseum to return these lost artworks to the museum space in an augmented reality through virtual technology.

Fig.5.15: "The Tree of Life" , Museum of Applied Arts in Vienna

Cuseum is an American startup company that develops products such as mobile applications, digital membership cards, and an augmented reality platform for museums, public attractions, and cultural nonprofits. Especially in the field of AR, Cuseum has cooperated with many museums and organizations completed many digital projects, such as "The Tree of Life" in Museum of Applied Arts in Vienna (Fig.5.15). For AR, the company's attitude is: *"With augmented reality, you can seamlessly blend digital objects and information with the real-world around you, and deliver completely new experiences to your visitors."*[1]

1. https://cuseum.com/augmented-reality-for-museum

Concept:

-Inspiration:

This project is designed and developed by Cuseum, which is located in Boston, same as the Isabella Stewart Gardner Museum. So the company decided to

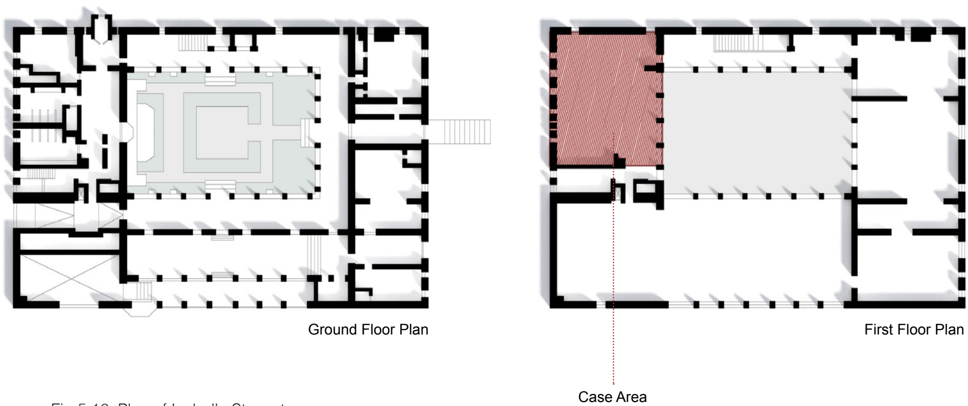


Fig.5.16: Plan of Isabella Stewart Gardner Museum
Source: Made by Author

do something for this museum. After some research, they found that many visitors to the museum either had no idea about the heist or didn't know what the looted works looked like. So the problem to be solved gradually becomes clear: "how could the technology help visitors see what is no longer there?" Using AR could be one of the best solutions. Attaching virtual digital information while maintaining maximum respect for the original museum space, and allowing this virtual information to be communicated to visitors through immersive interactive methods, became the primary source of inspiration for the project. With this concept and their love for this local museum, they decided to put their AR technology to use. They wish for the safe return of the stolen art, but in the meantime, they hope this project can instil feelings of wonder, hope, and inspiration.

- Strategy:

Mature application of AR technology provides the opportunity to put the stolen art back to their original frames. The Apple's ARKit has many advantages in the combination of virtual images and real space and provides technical support. Attempts and explorations of new technologies are the company's long-cherished goals. Combining new technologies in the digital field with the museum culture is also the company's main direction of cooperation. Before this project in Isabella Stewart Gardner Museum, Cuseum has already tried to use ARkit and make some applications in other museums. Good users' feedback, Familiarity and experience with AR technology provides the possibility to turn concepts into reality. Cuseum's strategy for the project is to simplify the user's operation as much as possible so that the process of using the application cannot to destroy the user's experience in the exhibition space. They expected when a camera on iPad that's loaded with the company's app is aimed at the spaces where the paintings were, the images appear on the screen, as if they were actually on the wall. "It's very seamless in that there are no buttons or complicated interface," Brendan Ciecko, chief executive and founder of Cuseum, said, "You're literally holding up your device and overlaying the paintings that would have previously hung in the frames."

- Project:

There are no particular difficulties in the implementation of this project. In terms of technology, to "place" the digital version of the artwork in the original frame only requires the camera of the device (iPad in this case) to capture the target object (picture frame in this case), and then the digital information will appear in the right position, At the same time, virtual objects will find corresponding perspective changes based on the user's position and visual angle to achieve the purpose of augmented reality. From an experience perspective, minimizing the tedious steps of user operations is the primary goal of this project. So in the use of APP, this project cancels all unnecessary buttons and operations. As long as users run the app, users don't need any other buttons to start the experience journey.

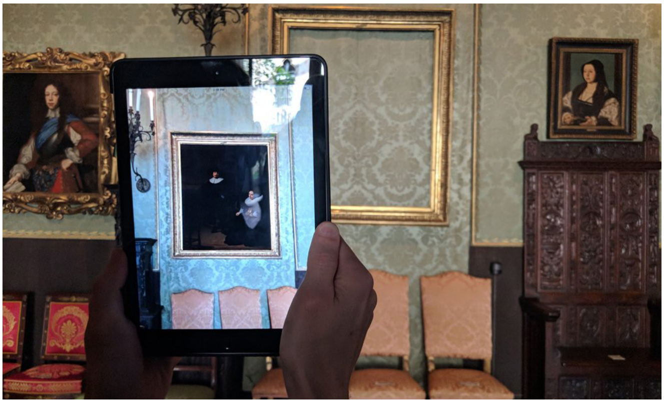


Fig.5.17: Frame in iPad Screen and Museum Space

-Relationship:
The designer plays a leading role in this project, whether it is the concept proposal or the final implementation, including later operation and maintenance. The designer first created creative motivation through understanding the technology in his field and caring for the local museum, and through cooperation with the museum, this motivation and concept were transformed into practical application projects. It is different from the traditional project model: that is, the client (museum) puts forward the requirements and the design team completes and perfects its needs. As shown in Fig.5.18, the project is a bottom-up design relationship and process: the design team takes the lead in proposing a possibility and presenting its prototype to the client to obtain the client's determination and conditions to realize their project.

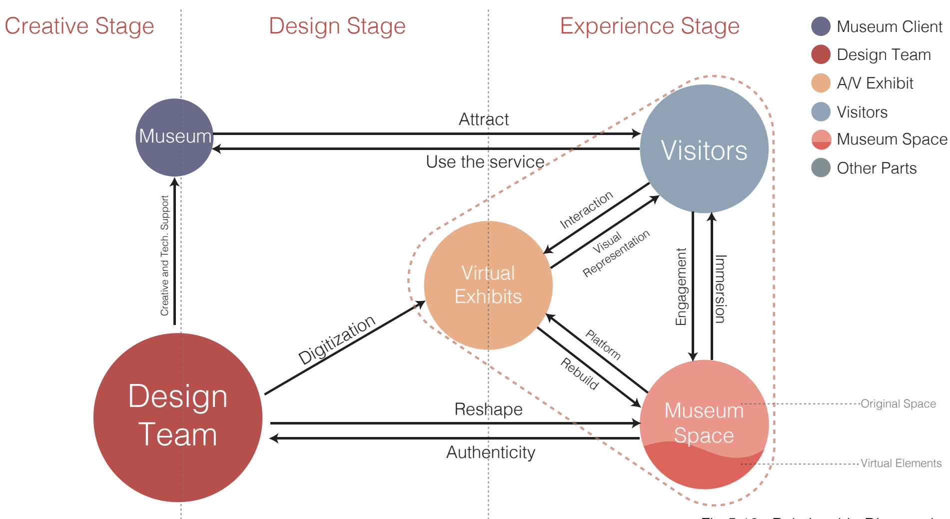


Fig.5.18: Relationship Diagram in "Hacking the Heist"
Source: Made by Author

Analysis

-Space:

The original space of the museum and the new space in the augmented reality environment are not very different in this case. In fact, it only restored the stolen artwork in the existing picture frame through digital method. At this time, people will think of a problem: "What is the essential difference between this and placing a copy in the picture frame?" However, the fundamental reason for the difference in actual results lies in the authenticity of space. In today's highly developed Internet, people can easily obtain all kinds of information about artworks, including high-resolution, detailed digital archives. In this context, authenticity in museums, especially art museums, is an important reason for attracting users to visit the physical museums. It is undeniable that works of art have a unique "aura" (Benjamin, 1935), but mechanical reproduction has lost "aura" to copies of works of art. At the same time, as an incubation container for works of art, the museum space which created by architects also has its "aura", that is the authenticity of space.

In this case, artworks were stolen, and legacy frames became one part of the history of this museum space. In order to respect this history and the artworks, the design team decided to use AR to reach a balance: not only keep the space as before, but also show the missing artworks to visitors. The generation of

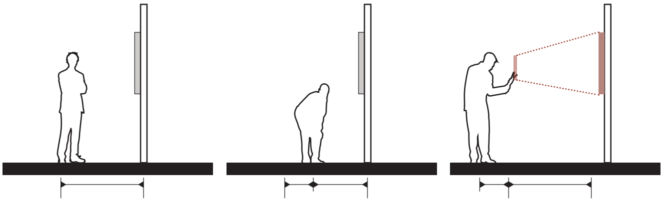


Fig.5.19: Diagram: Different distance in visiting artwork with and without handheld device
Source: Made by Author

augmented space changed the vistors' behaviros in original museum and also the spatial scale in the communicaiton between vistors and exhbits. As shown in Fig.5.19, due to the advent of handheld devices, forcing visitors to increase the distance from the artwork, this change of communicaiton scale will bring a new experience in augmented space.

-Technology:
In this case, the technology used by the designer team is object recognition AR. The core point of this AR technology is to define the target objects and the replacement objecst. Obviously, in this case, the target objects are the frames on the wall, and the replacement objects are the digital version of the two pieces of lost Rembrandt's artwork "A Lady and Gentleman in Black" (Fig.5.20) and "Christ in the Storm on the Sea of Galilee" (Fig.5.21). The difference sizes and some features of frames (Fig.5.22) ensures that the correct artwork will appear in its its corresponding frame. Because the entire APP contains only these two missing artworks, this allows the APP to run smoothly and accurately, reducing the possibility of bugs. Such a result will not cause additional distress and confusion for visitors during use. *"Technology, just like art, can give us a lens into a world that doesn't exist*

Fig.5.20: "A Lady and Gentleman in Black"

Fig.5.21: "Christ in the Storm on the Sea of Galilee"

Fig.5.22: Different frames as target objects

and expose us to concepts that broaden our minds," Ciecko said. *"My team and I spend a lot time thinking about how art and technology intersect and how the lines between physical and digital are becoming increasingly blurred."*

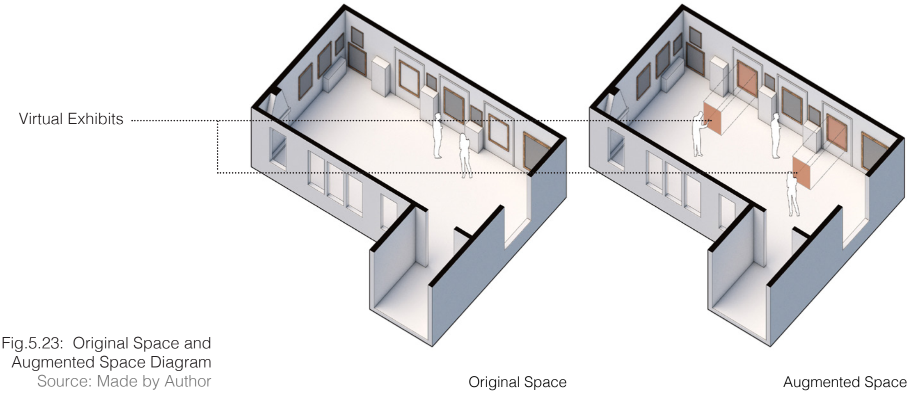


Fig.5.23: Original Space and Augmented Space Diagram
Source: Made by Author

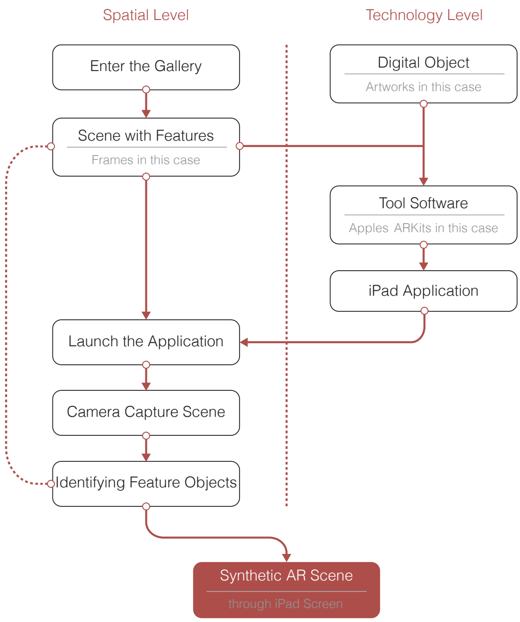


Fig.5.24: Spatial level and tech. level work flow in this case
Source: Made by Author

- Experience:
Although the project did not make much changes to the original space, this experience is indeed novel and interesting. According to the museum, many visitors do not know about the heist when browsing the artwork. Even if they find empty frames, they don't know the story behind the original paintings in these frames. Only a small number of people will read the texts in these frames and understand the truth of the matter. The use of this APP has effectively improved this situation. Thanks to the intervention of smart devices, visitors are more willing to participate in this interaction. In the process of using this enhanced space, visitors can not only understand the detailed introduction of the artworks and the heist, but also appreciate the significance of the empty frame in the museum space. Digital artwork is no longer a flat content on the screen, but can actually be dynamic related to the real space. The museum space, empty frames, and augmented exhibits constitute an authentic experience with "aura".

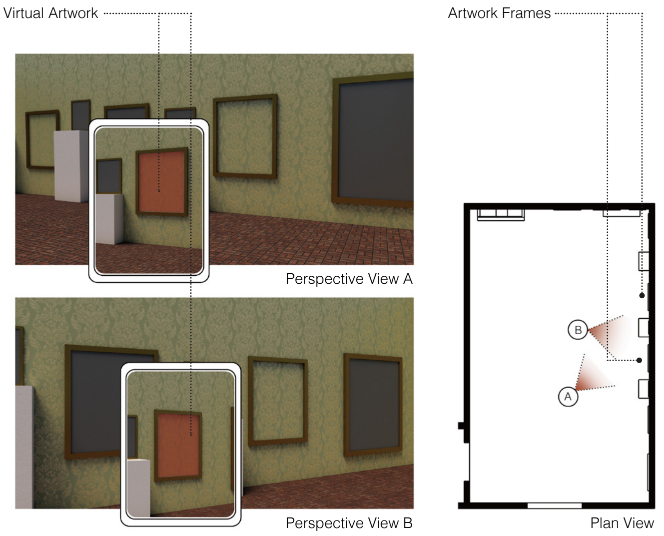


Fig.5.25: Original space and augmented space in different views
Source: Made by Author

Feedback

Once the project was exhibited in the museum, it aroused the love of the visitors. Before this exhibition, although there are instructions about the lost artworks in the museum, many visitors did not know the heist during the exhibition. Using digital lens and augmented reality to bring the lost great artworks back to original frame is not only a kind of modern representation, but also drives visitors to understand the history and the artwork, in turn stimulates the vitality of the museum. The audience's attitude towards the project is optimistic and positive. They are willing to try and share these experiences through the Internet social media, which brings a virtuous circle. And this experience is not the same as a virtual online exhibition, it must be in a specific museum space to get a complete viewing experience.

Based on his innovative application in the AR field in cooperation with art museums, many media, especially those related to the science and technology field (such as *Wired, Engadget, Artnet News* etc.), expressed appreciation for the project. The project team also said afterwards that it will participate more in art museums and AR virtual exhibitions, and bring more virtual visual technologies into more museums.

References

1. Cuseum, "Hacking the heist." Accessed June 19, 2020, https://www.hackingtheheist.com/

2. Swapna Krishna, "An AR app returns stolen Gardner paintings to their frames" Accessed June 19, 2020, https://www.engadget.com/2018-03-26-gardner-heist-stolen-paintings-arkit.html

3. Officical Site of Isabella Stewart Gardner Museum, Accessed June 19, 2020, https://www.gardnermuseum.org/experience

4. Tanskanen, Aapo, et al. "ARTIFICIAL INTELLIGENCE, AUGMENTED REALITY AND MIXED REALITY IN CULTURAL

VENUES." Consolidated Assignments from Spring 2019 (2019): 80.

5. Clark, Laura. "Paintings without Frames: The Role of Augmented Reality in Art Galleries." (2019).

Fig.5.26: “Air, Land&Sea” Experience in exhibiton hall, 2017, Puntam Museum, Davenport, USA

Case3: Air, Land&Sea

Fig.5.27: Putnam Musuem Position

Putnam Museum

Design Team: INDE

Davenport, USA
2017

Fig.5.28: Putnam Musuem Exterior Building Photo

Museum Type: Science and Technology Museum
Tech. Type: Augmented Reality + Interactive
Tech. Devices: Projection Screen
Tech. Support: BroadcastAR 2.0 + INDE

Introduction

The Putnam Museum and Science Center which has almost 150 years history, is a museum located in Davenport, Iowa, United States. The museum mission is to inspire ideas, dialogue and interaction among people of all ages through entertaining experiences that connect them to history, cultures, nature and the environment, by preserving collections and presenting educational programs, films and exhibits. The museum exists to preserve our region's treasures, educate people of all ages in unique and lasting ways and connect people as they experience science, history, cultures and environments throughout time and across the globe. In 2017, They created an immersive exhibition named "Air, Land & Sea", Air, Land & Sea, INDE's large-screen Augmented Reality experience was a perfect fit for the Putnam, a museum and science centre where people connect with history, nature and ideas by doing and experiencing.

INDE is a UK company which creates products and experiences that inspire, entertain, inform and educate using augmented reality and computer graphics. The company has developed cooperation with many companies (such as Visa, Coca-Cola, Warner Brothers, National Geographic, etc.) on virtual vision technology. It has gained complete attention and recognition in the industry. INDE believes that virtual vision technology provides an opportunity to build a new connection between society and 3D content, and their core driving force and banner will be Experience Engineering.

Concept

- Inspiration:

Different from the traditional AR experience which almost used handheld devices, the museum hopes to break away from handheld devices such as mobile

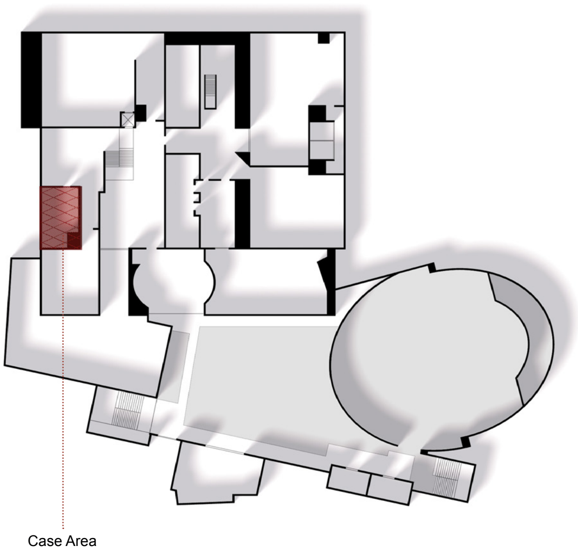


Fig.5.29: Plan of Putnam Museum
Source: Made by Author

phones and use technology to integrate virtual images and videos with the live audience through a large screen to form an augmented space experience.

INDE's BroadcastAR technology provided the possibility to achieve the objective, and It created in collaboration with the National Geographic Society, and the AR experience allows visitors to get up-close and personal with a diverse range of animals from Africa to the Arctic as they graze, drink, and interact with the environment around them. BroadcastAR instantly places the photo-realistic 3D versions of some magnificent creatures beside them and creates a life-like immersive experience by blending the real world with exceptionally high-quality digital content. The museum strives to achieve the following scenes: When visitors act in a designated area, images of wild animals and the image of the visitors appear on the screen. The image of the wild animals can be responded to according to the behaviour of the visitors.

- Strategy:

The museum finally chose BroadcastAR as the AR solution because of its unique use. The most significant feature of this technology is the use of a large screen as a visual output, rather than a traditional handheld device. In this way, the best experience for multi-user sharing can be achieved. The technology uses the camera to identify the users and their behavior. Then through the AR technology, the wild animal is merged with the real world as a virtual object. Finally, feedback to the visitors through the big public screen. In this usage scenario, the projection screen is equivalent to a giant mirror. When visitors enter the exhibition interior environment, the vast screen represents the form of combining themselves with the physical space. The visitors will subconsciously form a concept that the image on the screen is a reflection of the real world. At the same time, in this state, the audience will see their interaction with the space environment in the "mirror". On the basis of the above, the augmented reality is synthesized in the "mirror", and the user in the "mirror" is combined with the virtual environment so that the audience is immersed in the augmented environment(as shown in Fig.5.30). Visitors have more space for their vision and activities without the shackles of handheld devices; then they can be more immersed in the augmented space designed by the museum.

- Project:

Before this project, INDE has already cooperated with many companies in similar experience projects, which provided them with a more mature and practical project background. BroadcastAR has precise data requirements for space size and technical details, and the basic construction of the augmented environment

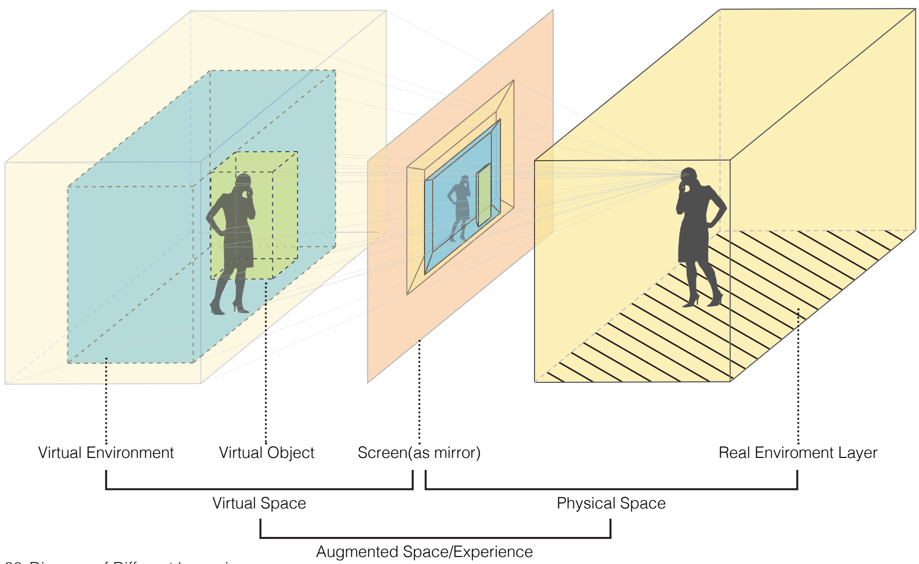


Fig.5.30: Diagram of Different layers in AR Room
Source: Made by Author

framework can be completed according to the INDE's guide. In terms of display content, the museum and INDE chose National Geographic as a partner, and National Geographic provided detailed data on wildlife and the environmental characteristics of their lives. Based on these scientific data and images, INDE not only produced exquisite 3D interactive dynamic biological models but also designed a virtual wild environment that matches the real space.

-Relationship:
INDE's innovation and success in other projects attracted the attention of Putnam Museum. In the perspective of the museum, BroadcastAR technology is the best choice which could provide an augmented space without smartphones. Driven by this innovation, the relationship between the audience and the exhibits in the museum has also undergone subtle changes. In the traditional sense, exhibits and visitors are relatively independent, and visitors' behavior towards exhibits

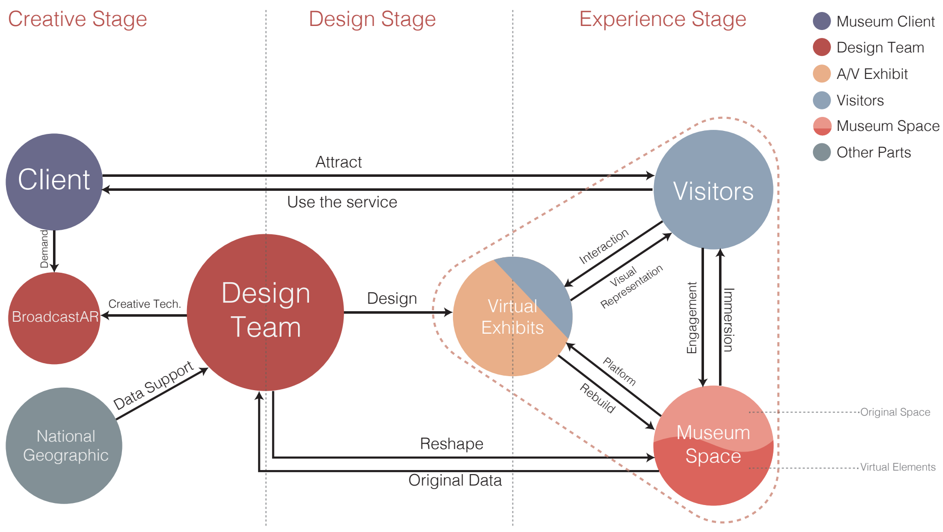


Fig.5.31: Relationship Diagram in "Air, Land&Sea"
Source: Made by author

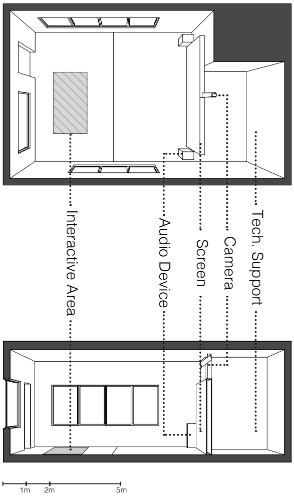


Fig.5.32:
Plan and Section of AR Room
Source: Made by Author

basically just stays at the level of observation. In this case, the image on the "mirror" is the exhibit which includes visitors, virtual animals and augmented environment. This means that users here are both observers and part of the exhibit (the relationship network as shown in Fig.5.31).

Analysis

-Space:

At the beginning of design phase, INDE has confirmed that BroadcastAR technology has an apparent demand for the layout of the space, the area of the exhibition hall should not be less than 50 square meters, and there is a fixed interactive area in the space. When the visitor steps into the interactive area to trigger the AR camera, the system will correctly build the reflection of the visitor himself with virtual objects on the display screen.

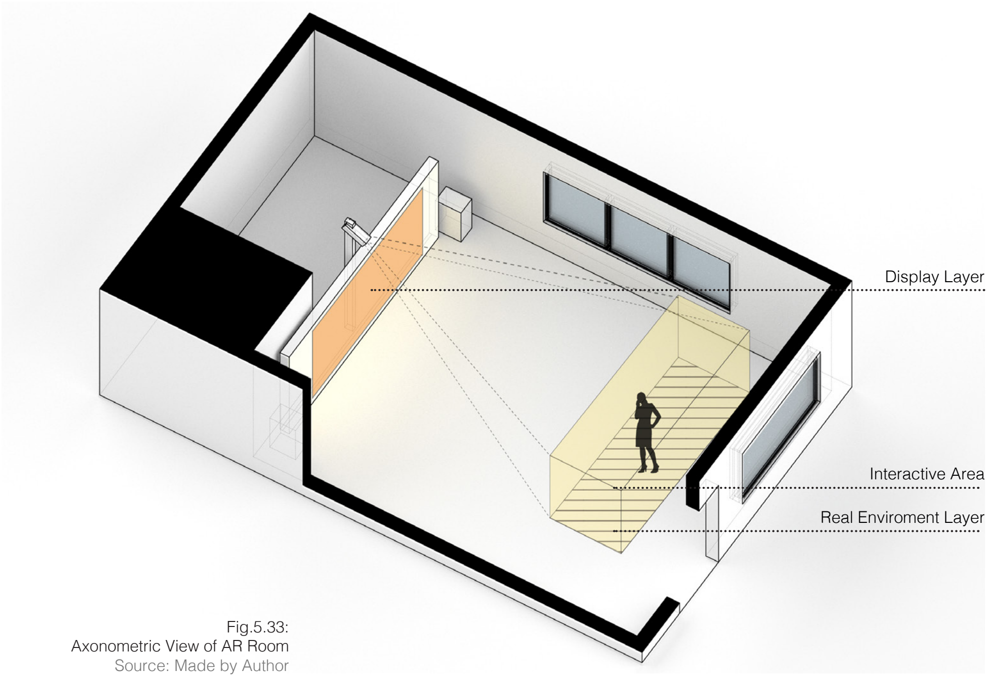


Fig.5.33:
Axonometric View of AR Room
Source: Made by Author

In terms of spatial layout, the museums use a separate room as a dedicated AR exhibition. Independent and enclosed space environment provides a good platform for AR systems, and the overall dark layout allows the visitors to pay more attention to the display of the screen instead of the original empty space. At the level of spatial perception, due to the existence of the "mirror", visitors will be focused entirely on the screen when using AR. In the digital environment creation, virtual technology converts the original ground in the space into other materials (such as grasslands or ice born), which actually feels a new spatial material for visitors. Although their feet are real floors, and in their subjective consciousness, this kind of ground material has become stone or ice. This is the immersion brought by virtual technology.

-Technology:
In this case, technological innovation can be said to be the critical point: the projection screen is used as a "mirror" ingeniously, and the augmented space represented in the "mirror" is used to restitute to the visitors. It is precisely because of the innovation that visitors can break away from personal handheld devices and have a better experience of the immersion brought by the augmented environment. The communication effect obtained by this immersion, convenience and entertainment makes the whole space more dynamic. Essentially, this technology is not very different from AR systems used via mobile phones. The fundamental difference lies in the objects and carriers. In daily AR usage scenarios (mostly using mobile phones as tools), users obtain spatial content through mobile phone cameras. However, due to the relative position of the mobile phone screen and the camera, users can hardly see their own images on the screen, which causes themselves to be isolated

from the augmented environment. In other words, the handheld AR technology forcibly separates the user from the virtual space, and the user can only play the role of observer behind the monitor instead of actively participating in the virtual space. The project transforms the use of subjects and objects. The entire space is captured by a camera placed in the exhibition hall. The visitors and the original space together form a background layer, and the background computer attaches the virtual three-dimensional object and environment as an overlay information layer to the background layer. Finally, this composite image is output on the projection screen. If we compare this technical form with the well-known mobile AR application: the backstage of the exhibition hall is equivalent to a mobile phone processor; the projection screen is equivalent to a mobile phone screen; the user-exhibition area is equivalent to the spatial information obtained by the mobile phone camera.

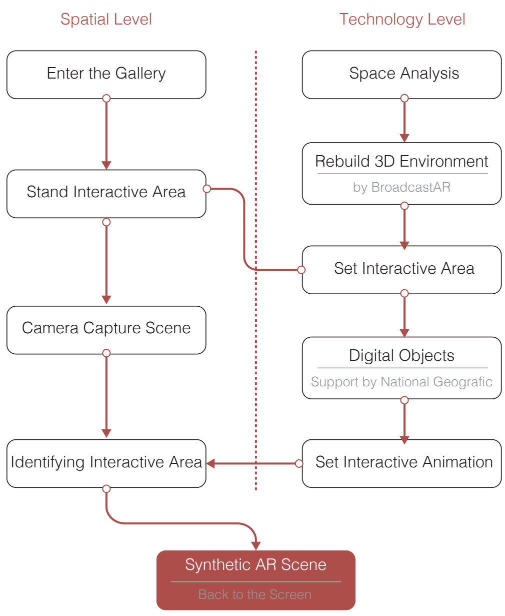


Fig.5.34: Spatial level and tech. level work flow in this case
Source: Made by Author

- Experience:

BroadcastAR technology is not a completely disruptive technological revolution, and It can even be said that it is just a kind of AR technology that is slightly different from the widespread recognition of the masses. But the experience innovation brought by this change is indeed obvious and worthy of expectation. Users can free their hands to interact with substantial virtual objects in an "empty" showroom. The virtual space background generated by the AR technology is well combined with the original space and can recognize the human body to give the correct occlusion relationship. This screen acts as a mirror, except that it reflects a variety of virtual elements in addition to reflecting the user's real state. From the general cognition of the user, the object in the "mirror" should be truly present in the current space. In fact, the exhibition hall is empty, this excellent relationship brings an augmented experience

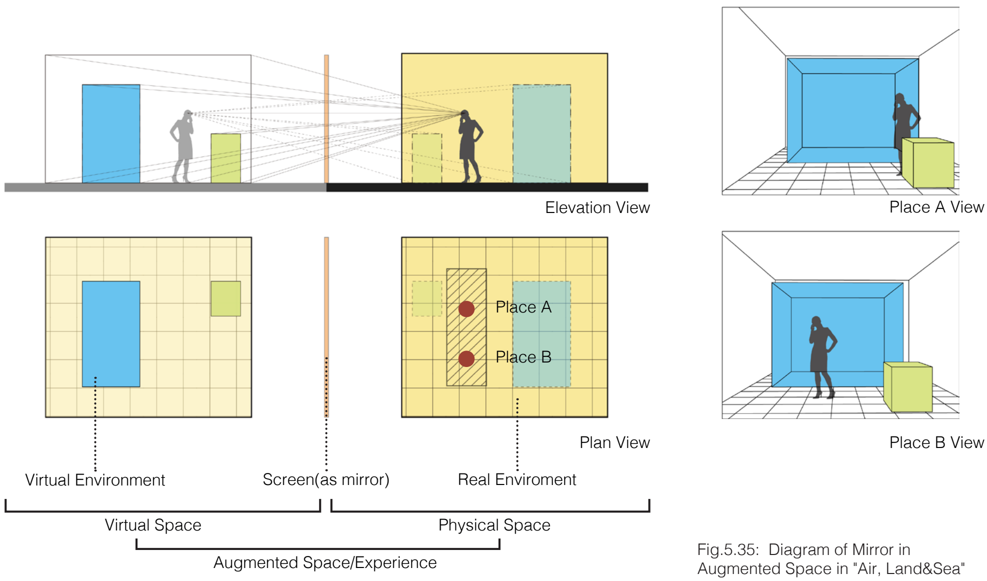


Fig.5.35: Diagram of Mirror in Augmented Space in "Air, Land&Sea"
Source: Made by author

to the user, and the experience of the original space is raised to a new field through virtual technology. In the subconscious, this also brings visitors a kind of thinking, that is, when the space perceived by users is different from the real space, how can visitors accept, trust and participate in the new space they perceive.

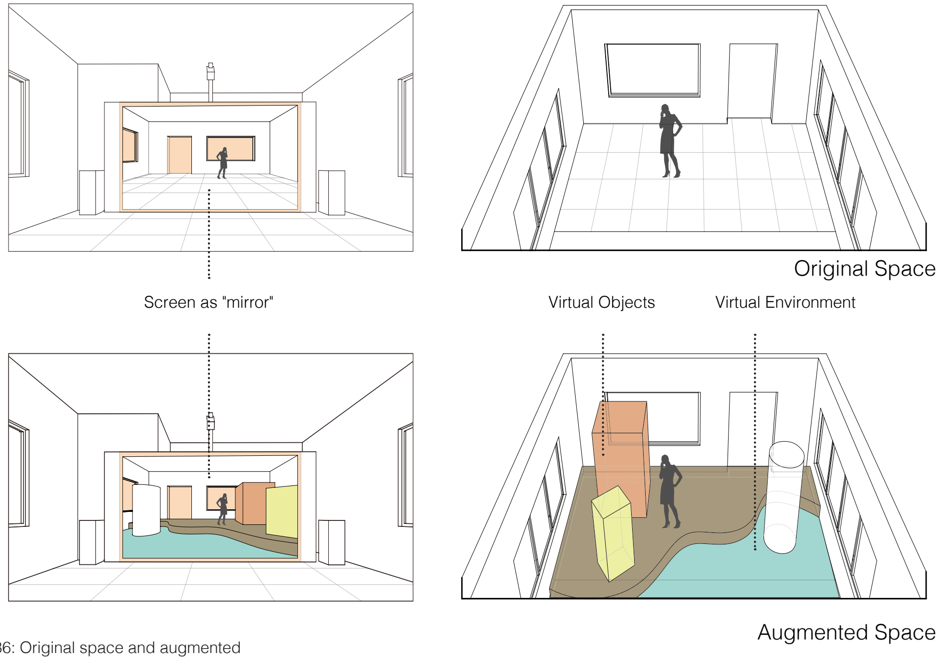


Fig.5.36: Original space and augmented space in this case
Source: Made by Author

Feedback

This fresh experience has a strong appeal in the Science and Technology Museum, especially for children. They show great energy and participation in the process of using the AR experience. For virtual objects (such as elephants, penguins, etc.), children are happy to interact with them. At the same time, they can observe the results of this augmented space from the big screen in real time. This kind of instant, high quality feedback is positive for the user experience. Because of this AR space combined with self-display, visitors are more willing to share their moments of interaction with virtual animals on social media.

The success of AR technology innovation also prompted INDE to cooperate with other museums and exhibition halls in many similar projects (such as *Eröffnung Huawei Green Planet*, and *Coca-Cola Arctic Home Campaign*). According to users' posts and messages on social media (Basically on *YouTube, Twitter* and *Facebook*), it can be seen that this type of project is very attractive: The persons who have participated are willing to share this unique experience on the Internet, while the others who have not participated want to actively integrate and try this experience. This is the charm of augmented space.

References

1. INDE, "BroadcastAR" Accessed June 29, 2020, https://www.indestry.com/broadcast-ar

2. Putnam Museum Offical Websitd, Accessed June 29, 2020, http://www.putnam.org/

Fig.5.37: “Step Back in Time” Experience in exhibiton hall, 2017, National Museum of Singapore

Original Space — Augmented Level Medium — Virtual Reality

Case4: Step Back in Time

National Museum of Singapore

Design Team: GuidiGo&Google
Singapore City, Singapore
2017

Museum Type: Comprehensive Museum
Tech. Type: Augmented Reality + Interactive
Tech. Devices: Lenovo Phab 2 Pro phone
Tech. Support: Google Tango

Fig.5.38: National Museum of Singapore Position

Fig.5.39: Photo of National Museum of Singapore

Introduction

The National Museum of Singapore, known as the Singapore History Museum, which was established in 1849 is the oldest museum in Singapore. Beneath its 19th-century colonial exterior, it uses cutting-edge technology to present the nation's legacy and development. Its galleries highlight fresh perspectives of the Singapore story as they take visitors on an immersive voyage – one where creative storytelling redefines the conventional museum experience. As a cultural and architectural landmark in Singapore, the National Museum always maintain a positive attitude towards the support and introduction of emerging science and technology.

In 2017, cooperating with Google and GuidiGo, using the most advanced Tango[1] AR technology at the time,

1. Tango was an AR computing platform, developed by the Advanced Technology and Projects, a skunkworks division of Google. The purpose is to give the human body's perception of activities and the surrounding environment to mobile devices.

the National Museum offered a special AR exhibiton "step back in time" showed the history of the iconic building. Using indoor mapping and AR technology, visitors will be able to explore how the building has evolved over the past 130 years and virtually view artefacts that were once on display in the museum.

As the designer of AR content, GuidiGO is a publishing platform for creating next creative tours on mobile devices, and it has designed and set up more than 50 augmented reality experiences for museums and cultural institutions around the world. This case "step back in time", is one of his representative works.

Concept

- Inspiration:

The National Museum of Singapore is among the first museums in the world to adopt Tango. It takes a certain degree of courage to choose an unknown new technology as the representation tool for an importatnt exhibition when museums have not widely

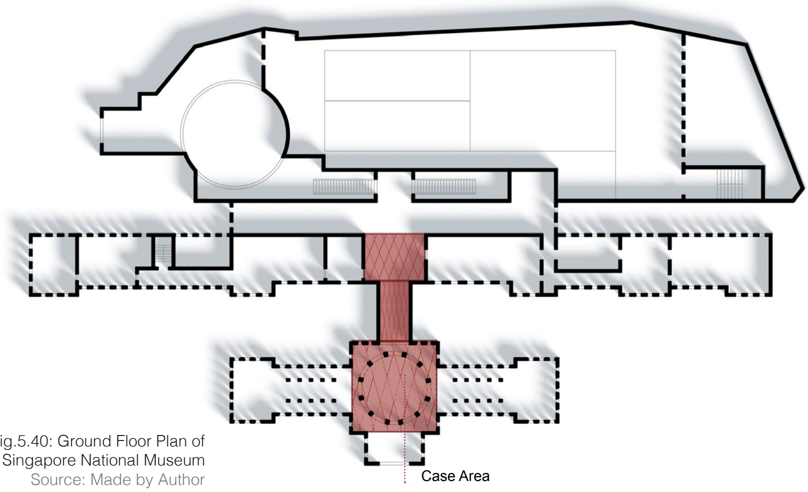


Fig.5.40: Ground Floor Plan of Singapore National Museum
Source: Made by Author

use virtual technologies. The attitude of the museum is quite commendable, as the museum's director, Angelita Teo, said: *"The emergence of digital and future technology has opened many doors for museums worldwide and we now have the opportunity to redefine the conventional museum experience."* The National Museum has profound historical and cultural connotations, not only because many exhibits which are always noticed by visitors in the collection are historical relics. However, the history of the museum itself and the stories behind the vicissitudes are often ignored by tourists. The museum hopes to turn back time, reproduce the important changes in the museum's architectural space during the history process and show how the museum has changed over time through Tango AR technology. This is also Teo's original intention for the project: *"enhanced architectural tours will enrich our visitors' experience of our stories and their connection to the past."*

Fig.5.41: Photo of National Museum of Singapore

- Strategy:

The museum initially planned to find several landmark and important attractions in the venue space. Highlights include a virtual reconstruction of the 90-feet high dome Rotunda at the main entrance as it was in the 1950s, complete with the artifacts that were on display then. These virtual scenes will be closely integrated with the real space in mobile phone screen. This means that not only the virtual exhibits will appear in the places where they once exhibited, but all the architectural elements will be restored to the historical period as much as possible. For example, in tdome Rotunda, when visitors observe the floor tiles with their mobile phones, they will find that the original floor tiles patterns are different from the current ones (as shown in Fig.5.41). On this basis, the museum also plans to add a virtual navigation system (Fig.5.42), Through the

Fig.5.42: Photo of National Museum of Singapore

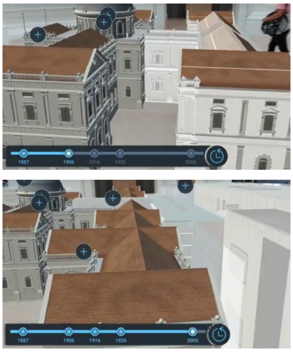


Fig.5.43: "Step Back in Time" Experience in exhibiton hall, 2017, National Museum of Singapore
Source: Screenshot from https://www.youtube.com/watch?v=V6bo-AKiUNg

combination of positioning system and virtual elements, visitors can be guided to the exhibition hall they want to visit in real time on the mobile phone screen. At the same time, the museum also set up a reduced-scale museum architectural model in the virtual tour. The model is attached with a time bar. Visitors can adjust the time bar to encounter the changes of the building in different time periods (as shown in Fig.5.43).

- Project:

This project took several months to complete. GuidiGo worked with Google and the National Museum. In order to build a virtual prototype that fits in with the original space, the production team completely scanned the original museum space and digitally reconstructed

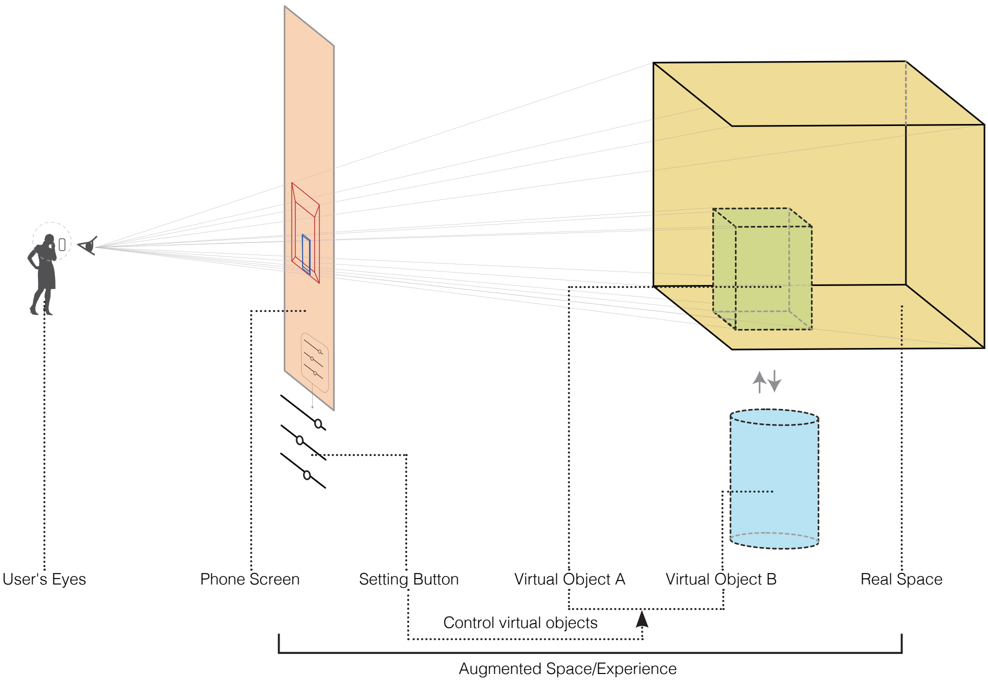


Fig.5.44: Diagram of view in this case
Source: Made by Author

the 3D information model. GuidiGo has studied a large number of cultural relics and historical photos from museum to make the best to give the best experience for visitors. The Tango technology provided by Google also played an essential role in this case. Tango technology and equipment have a stronger ability to recognize space and objects, coupled with an accurate positioning system, can quickly and accurately represent virtual elements on the phone screen in a default space.

The project is not just an AR project in a single space, but a combination of different places and navigation systems. This brings a certain degree of difficulty to the completion in the project. Although virtual vision technology encourages users to interact with virtual exhibits with real-world interaction logic, we have found in many AR projects that users still like to stand in place to observe the mobile device in their hands. However, in this project, the design team used a navigation system to connect the virtual experiences of different areas to form a series of virtual tours.

- Relationship:

The attractiveness of advanced technology is a major factor in the success of this project. In fact, in 2016, the museum has organized docent-led Architectural Tours which provide insights into these stories and the hidden history behind the Museum’s building. The addition of Tango-enabled smart devices to the tour will now complement the stories told and allow tour participants to better visualise the tales with the help of smart devices. Due to the particularity of the augmented exhibits, the relationship network has produced subtle changes in users, exhibits and museum space. The vast content of virtual exhibits is a reproduction of the historical museum space, which means that the space itself is both the exhibit and the container of the exhibit (as shown in Fig.5.45). This contrast between the past and the present, the virtual and real space, the technology and the culture will bring visitors a unique experience.

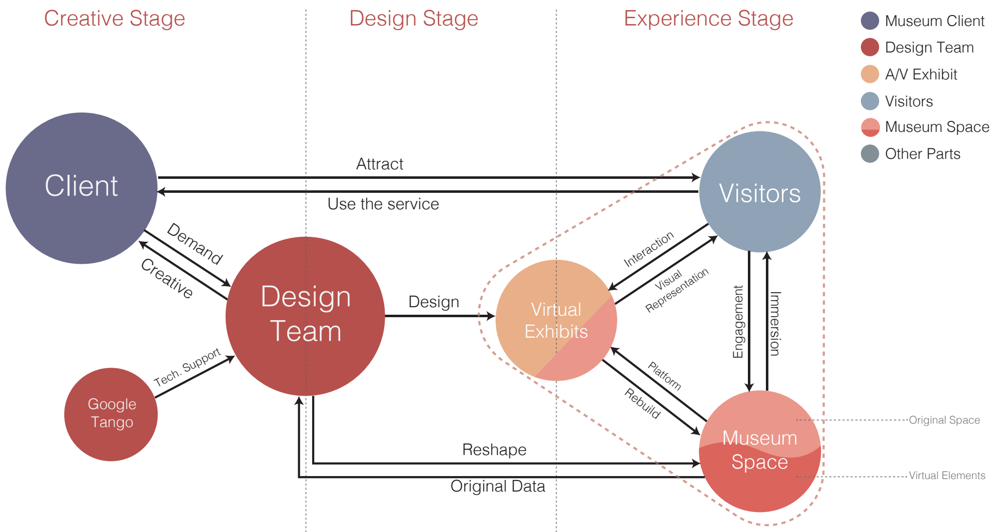


Fig.5.45: Relationship Diagram in "Step back in time"
Source: Made by Author

Analysis

- Space:

In architectural interior projects, most spaces are presented as vessels. The content carried by this container is rich and varied. Space can be understood as the vessel of light (Richard Rogers), or the container of events, people and society (Kazuyo Sejima). In museums, the role of space as a vessel is obvious. Funtionally speaking, the core function of the museum space itself is to collect and display exhibits. In terms of behavior, visitors as participants in space activities, their interaction with exhibits and other people is captured by the museum interior space. However, space itself is often overlooked in museums. So, if the space is both the vessel and the content in the vessel, will this situation improve? In this case, an important component of the exhibit is the change and state of the space in the past decades. AR technology reproduces this historical trace in the current space, and this interesting dialectical relationship has upgraded the role and function of the current museum space. It is not only a container for exhibits, but also a virtual exhibit with contrast and dynamic changes under Tango technology.

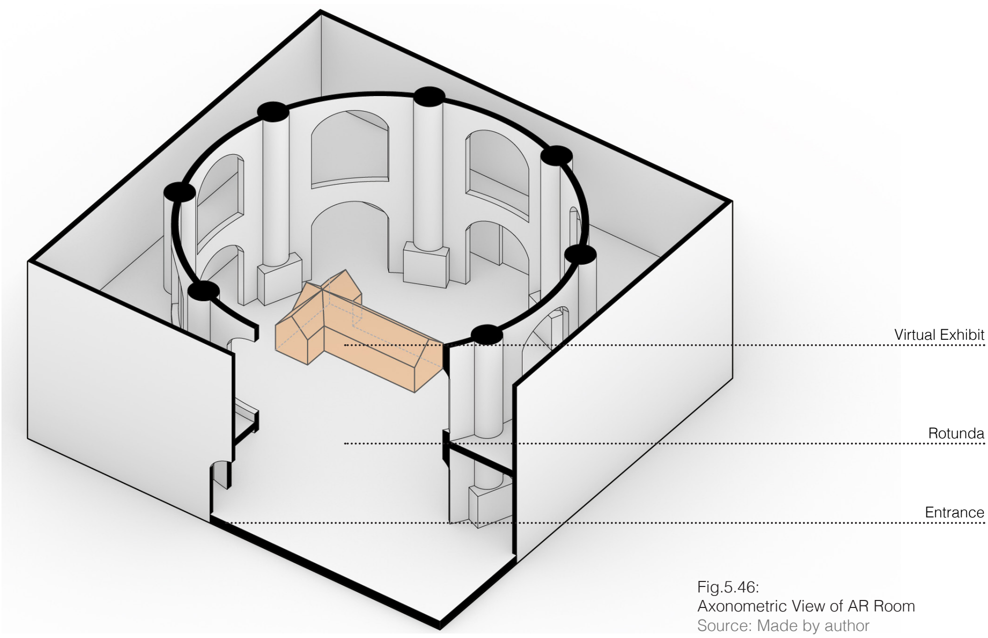


Fig.5.46:
Axonometric View of AR Room
Source: Made by author

- Technology:

This case uses the most advanced handheld AR technology, Tango AR, at the time. Compared with the immature mobile AR application in 2017, Tango's AR technology has three distinct advantages: The first one is precise motion-tracking system. In combination with accelerometer and gyroscope data, Tango can quickly and accurately identify the displacement and rotation of the visitor during the use of the application, which can make the virtual object appear on the phone screen in a more correct perspective; The second is a highly accurate area learning system. that ensures that users get different feedback at different locations (such as real-time map guidance). Based on these advantages, it is easier to respect and enhance the augment space. When the phone detects a specific location, the corresponding content is displayed on the screen; The third and most distinctive advantage is its depth perception, which means the camera can identify the spatial position with high precision. The above advantages are fully demonstrated in this project which shows a lot of virtual elements based on physical museum space. Accurately identifying the site and enhancing the space will give visitors a refreshing feeling. At the same time, the navigation system also helps stimulate visitors' desire to explore.

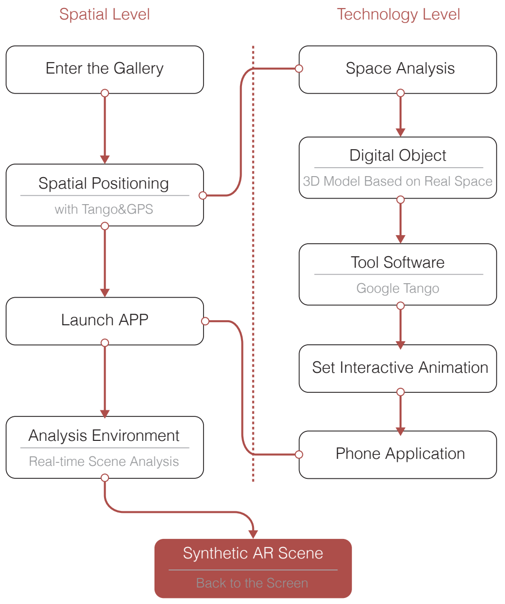


Fig.5.47: Spatial level and tech. level work flow in this case
Source: Made by Author

- Experience:

Thanks to Tango's innovation in the AR field and hardware support. The best experience that the AR gives to the audience in the experience is the sense of substitution and immersion. The virtual objects generated by the mobile phone will appear on the screen in real logical interaction (as shown in Fig.5.48). Under Tango technology, this virtual element can accurately and quickly identify the replaced object. The recognition of space and characters makes this virtual experience more realistic. The augmented space in the screen and the real space outside the screen provide a new immersive experience. From the perspective

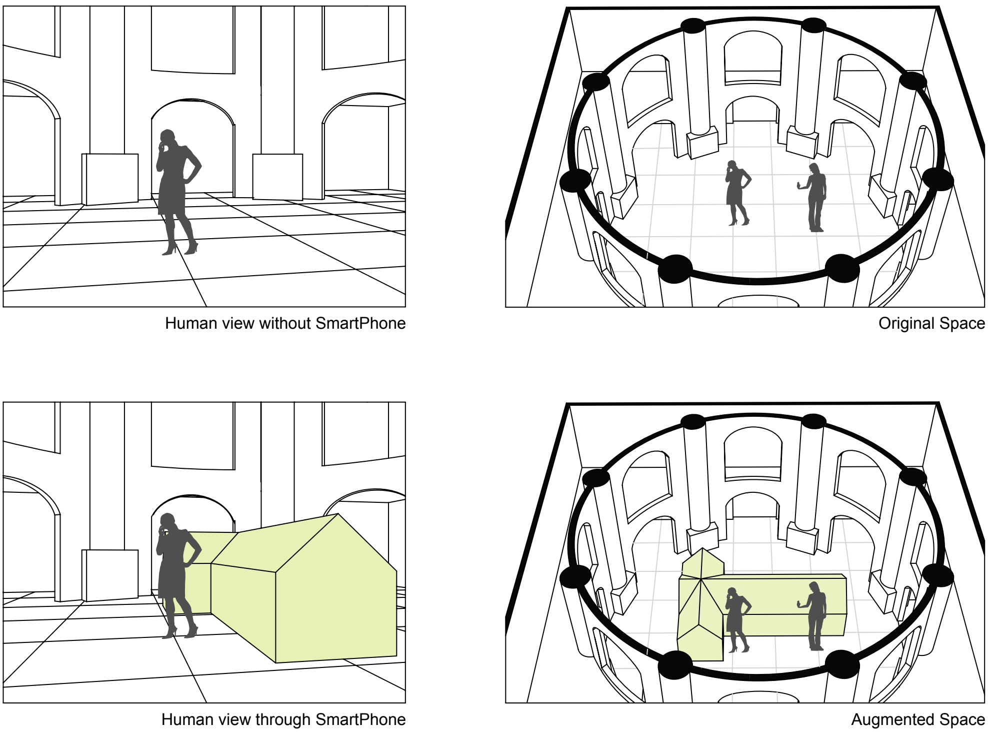


Fig.5.48: Diagram of Augmented Space in "Step Back in Time "
Source: Made by Author

of the observer, it is only seen that the user observes the mobile phone in the hall and cannot see the exhibit. The AR technology that can only be triggered at a given location enhances this desire to explore. Entertaining and exploratory are attractive to museum visitors. Compared to the traditional way of introducing history such as texts and images, using AR exhibition to tell the story behind the historical buildings and their vicissitudes, visitors will be more willing to understand and experience.

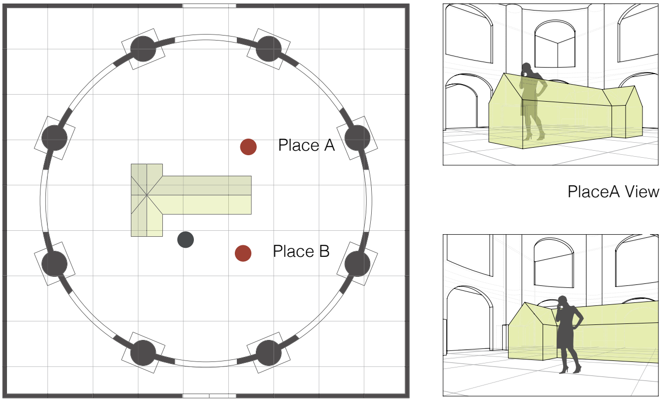


Fig.5.49: Diagram of Augmented Space in "Step Back in Time "
Source: Made by Author

Feedback

The National Museum of Singapore is one of the first museums in the world to adopt Tango technology. In the early days when virtual technology began to be active in society, "Step back in time", as a practical project with a breakthrough in technology, was reported by many Singapore media (such as *The Straits Times*[1]) and technology media. The success of this project proves that through the use of new technologies, the museum can reach a new level of experience. Facing this circumstances, The museum director said*:" This is just the beginning of what we are able to do with Tango and its virtual and augmented reality technology*

1. The Straits Times is an English-language daily broadsheet newspaper based in Singapore and currently owned by Singapore Press Holdings.

at the National Museum of Singapore. We will continue to build on this tour experience with more content, and also explore more ways to harness this technology for unique experiences for all visitors." Thanks to the benefits of technology, after this project, more and more virtual visual technologies have been presented into the Singapore National Museum such as *DigiMuse Open Call* and *Digital Showcase.*

Fig.5.50: Visitors attempt to conserve a painting with the HoloLens as part of "Project Insight" by HelloHolo, presented as part of the DigiMuse open call in 2018.
Source: https://www.nhb.gov.sg/nationalmuseum/research-and-publications/resources-and-publication-list/musing---nms-blog/digimuse

References

1. GuidiGO, "BroadcastAR" Accessed August 15, 2020, https://www.guidigo.com/ar

2. Singapore National Museum Offical Website, Accessed August 15, 2020, https://www.nhb.gov.sg/nationalmuseum?sc_lang=en

3. Ooi, CanSeng. "Dialogic Heritage: Time, Space and Visions ofthe National Museum of Singapore." *Interconnected worlds: tourism in Southeast Asia (2001).*

4. Nabilah Said, "National Museum of Singapore uses augmented reality to tell building's history" Accessed August 15, 2020, https://www.straitstimes.com/lifestyle/arts/national-museum-of-singapore-uses-augmented-reality-to-tell-buildings-history

Fig.5.51: “Invasive Species”, 2017,
Perez Art Museum PAMM

Case5: Invasive Species

Pérez Art Museum Miami

Design: Felice Grodin
Miami, USA
2017-2019

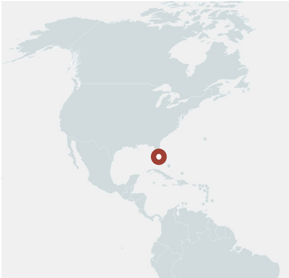


Fig.5.52: Pérez Art Museum Miami

Museum Type: Art Museum
Tech. Type: Augmented Reality + Interactive
Tech. Devices: iPad, iPhone
Tech. Support: Cuseum

Fig.5.53: Pérez Art Museum Miami

Introduction

The Pérez Art Museum Miami (PAMM) is a contemporary art museum that relocated in 2013 to the Museum Park in Downtown Miami, Florida. It was designed by famous architects Herzog & de Meuron. Considering the unique functionality and specificity of the contemporary art museum in Miami, which is known for its modern art and decor, many ingenuities are added to the design. Herzog & de Meuron think the museum is not an isolated "jewel box" for art lovers and specialists, but provides comfortable public space for everybody. Therefore, PAMM has a large number of architectural elements combined with nature, such as the canopy, the platform and the columns. The veranda where filled with vegetation occupied the entire site. According to the different attributes and contents of the exhibits, the spatial organization of the museum is organized for different types. In order to provide a place for communication and viewing, the museum designed many open and semi-open public spaces where also host temporary exhibitions.

"Invasive Species" is a series virtually interactive, a digital exhibition composed of four AR projects by Miami-based artist Felice Grodin from December 2017 until 2019 in PAMM. The exhibition uses AR technology; visitors can experience virtual 3D artworks and installations in the PAMM space through real interaction. Featuring four site-specific digital works, Invasive Species virtually interacts with PAMM's architecture and transforms the museum's environment as a response to Miami's ecological reality. As a contemporary artist with a background in architecture research, Her practice focuses on the integration of art by modelling the present environment (real space) and creating meaningful overlay (augmented reality) upon them.

Fig.5.54: Ground Floor Plan of PAMM museum
Source: Made by Author

Concept

- Inspiration:

Because of Felice Grodin's architectural studies background, she became interested in the relationship between mental and physical space. Under the dual effects of artistic acumen and rigorous architecture, Grodin began to create works of art that belonged to her with distinctive characteristics. Abstract hand-drawn landscape drawings and precise technical isometric begin to interact and merge in her artworks (as shown in Fig.5.55). It also made her reflect the interaction of nature and culture simultaneously. Since then, She realized that imaginary could be applied both in the virtual and actual sense. This kind of artistic viewpoint can be said to be a prototype of virtual art, to be precise, augmented art, that is, artistic creation is presented in real space through virtual visual technology. Augmented artworks are not only graphics on the 2D level; they even surpass 3D representation, and "appear" around us.

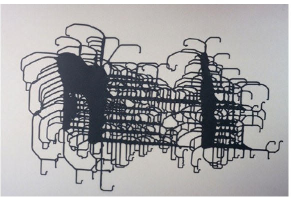
Fig.5.55: Felice Grodin, *WHERE ANGELS FEAR TO TREAD*, ink on Mylar, 42" x 64", (2008)

In 2017, the PAMM decided to pursue an augmented reality project featuring a local artist, Felice Grodin. It is worth mentioning that this project is not an ancillary exhibition, but primary programming of the museum. And it was the first full exhibition of augmented artworks around the world. This cooperation with PAMM demonstrates Grodin's extraordinary accomplishments in the field of augmented art, and also brings the success of the "Invasive Species" project.

- Strategy:

This project is worked by artist Felice Grodin and curator Jennifer Incacio. After many discussions, they hope to show the environment of South Florida through this project and explore the variability of landscape, architecture and our urban environment through artistic expression. They would adapt a similar strategy by exploring climate change in a speculative way. Augmented reality provides the possibility to merge future trends with current scenarios. How to better integrate digital artworks with the museum space through AR, and how users can better interact with these digital exhibits are issues that they need to deal with in their strategy. In the final, four impressive scenes were selected in the museum as the interactive space for the four works of art. To show the species invasion caused by environmental changes in the existing space and structure of the museum through augmented art which to express the instability and transformative of the ecosystem. In fact, many of her previous artworks reflect related topics, and in the exhibition, she needs to show her past artistic ideas to visitors through augmented reality.

- Project:
It is not accessible to turn a flat two-dimensional artwork into a digital artwork exhibited through augmented reality. It's not just about converting flat 2D graphics into 3D digital volume, but also needs to consider how and what form virtual objects exist in the established museum space; how the form of space relates to virtual art; and how the audiences participate in the art exhibition and interact with the augmented artwork.



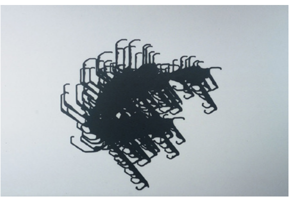


Fig.5.56: *LAMINAR* series, ink on Mylar, 2006

For example, the left image (Fig.5.56) is a series of artwork named Laminar created by Grodin. The work is also a prototype for one of the augmented works in the exhibition. After discussion and design, the work was exhibited in the auditorium of the museum. In order to integrate with the environment of the auditorium (a large number of stairs and a wide space), Grodin remade the painting to satisfy its existence in the real space in a way more in line with its artistic characteristics (as shown in Fig.5.57). At the same time, the work is also given "animation", that is, in the process of the display, the work is not static but dynamic. This is also an upgrade that AR can bring to artworks. In the end, the virtual objects presented on the screen are augmented artworks that are highly compatible with the exhibition space and have a certain degree of interaction (Fig.5.58). With the support of the systematic design and technical department, Grodin was able to show four different artworks to the visitors in the form of AR. When visitors use the app to reach the designated place, they can discover the virtual exhibits in the museum space through the screen.

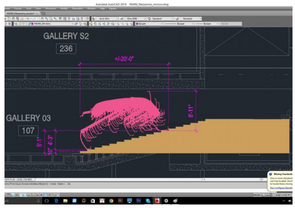


Fig.5.57: digital model work in progress

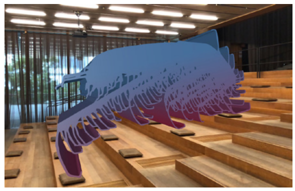


Fig.5.58: digital model work in AR exprience

- Relationship:

Different from the exhibits in science and technology museums or history museums, work in art museums are more subjective; that is, they reflect the artist's own understanding of the subject. This means that artists and curators often have more power in the design of exhibition spaces. They can decide what way, what medium and how to use the spatial structure of the exhibition hall to present the works of art. The authenticity of visual art has been challenged continuously after the invention of the camera. In the Internet age, works of art can be spread more widely, but the uniqueness of works of art has been lost. Augmented artworks are different. Although it is also an artwork with virtual vision as the main form, it does not have the possibility of being copied and spread on a large scale because it needs a specific place to carry it. More importantly, augmented artworks emphasize the viewing experience in original space, which is the place cannot be replaced easily in a digital way. The role of space in this case is self-evident. The design of Herzog&deMeuron pays great attention to the integration of indoor and outdoor spaces, to be precise the integration of natural and artificial environments. The thematic concepts explored in this museum space coincide with the artwork itself. It is accurate because of the subtle relationship between the space itself and the artwork that the overall exhibition experience has reached a new level.

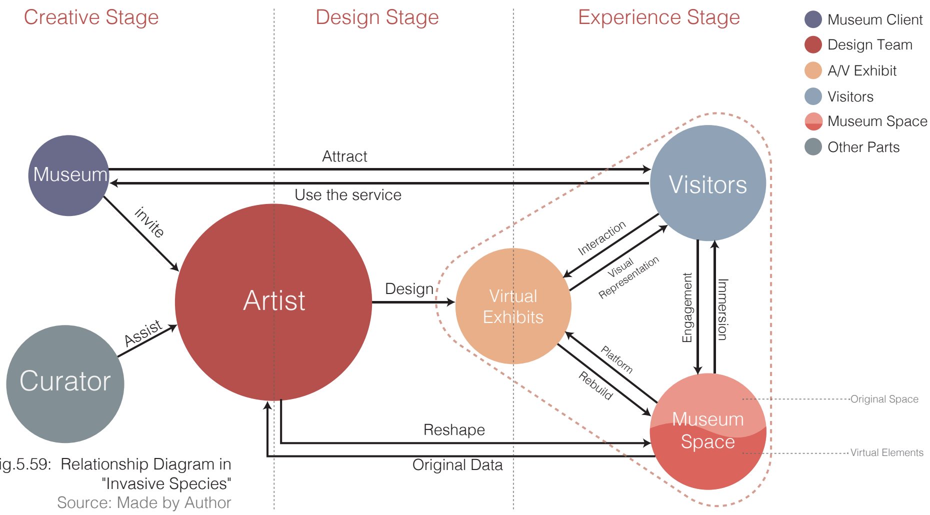


Fig.5.59: Relationship Diagram in "Invasive Species"
Source: Made by Author

Analysis

- Space:

"Invasive Species" uses virtual digital models to depict the impact of future environmental changes on the environment in the form of art, that is, digital "alien" creatures enter the museum space through augmented reality technology. Due to space limitations and the complexity of exhibits. This kind of large and imaginative exhibits have been realized in museums through installation art in the past. Compared with installation art, virtual technology has utterly different performance in the exhibition. Virtual technology itself can break away from the limitations of physical conditions, and it does not occupy the physical space of the museum. For example, in Fig.5.60, virtual exhibits almost spread across the entire museum platform. If this kind of exhibit is realized in the form of installation art, it can be imagined that this requires a high cost and completely occupies the public space of the museum. In this project, virtual art is not merely placed in a particular space of the museum. Its charm is that the 3D model of the virtual exhibits can "merge" into the real space of the museum. "Merge" means virtual exhibits need to identify the architectural space and make a correct response to its structure. When Grodin recreated these virtual objects, she needed to expect how it interacts with the structure in the real space. As shown in Fig.5.61, the virtual elements (symbols) are "accurately" generated in the indication of the building structure instead of being suspended. In order to create an artwork that fits with the environment, the designer should fully be understanding the architect's inspiration in space.

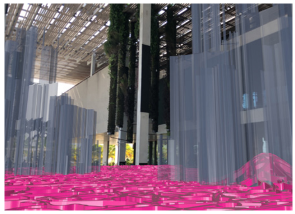


Fig.5.60: Terrafish, "Invasive Species" AR art exprience in PAMM
Source: Photo by Christian Bonet, Image courtesy of Pérez Art Museum Miami

Fig.5.61: Field Report 2518, "Invasive Species" AR art exprience in PAMM
Source: Photo by Christian Bonet, Image courtesy of Pérez Art Museum Miami

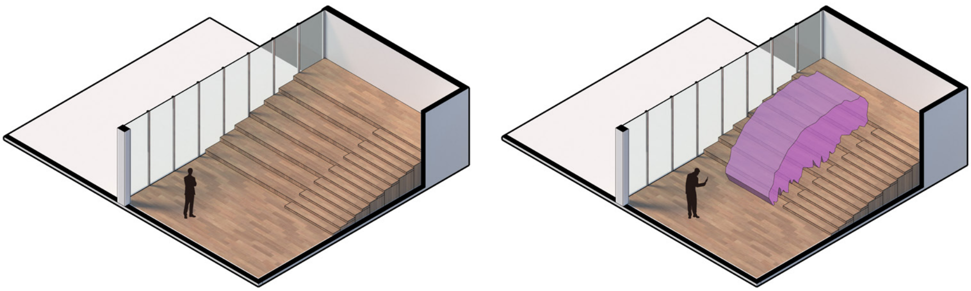


Fig.5.62: Axonometric View of AR Experience "Mezzbug" Interior
Source: Made by author

- Technology:

As mentioned earlier, the most significant technical challenge of this project is to place the artwork in precise spatial coordinates. This requires the application to be able to effectively recognize the architectural space. As technical support, the Cuseum company choose the relatively mature ARkit platform (made by Apple). Before the architectural space is matched, they also need to transform Grodin's artwork into digital form and transform it from two dimensions to three dimensions. On this basis, it is necessary to design additional animation controls to ensure that the virtual exhibits are not displayed in a static three-dimensional form, but are almost a complete remake based on the inspiration of the original artwork. Dynamically augmented exhibitions (as shown in Fig.5.63) not only relate to space but also form an interactive relationship with the visitors, thus creating an overall virtual experience relationship network.

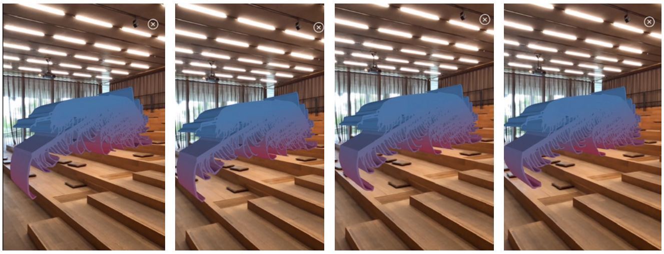


Fig.5.63: Screenshot of augmented exhibits animation, "Invasive Species"
Source: https://vimeo.com/271520062

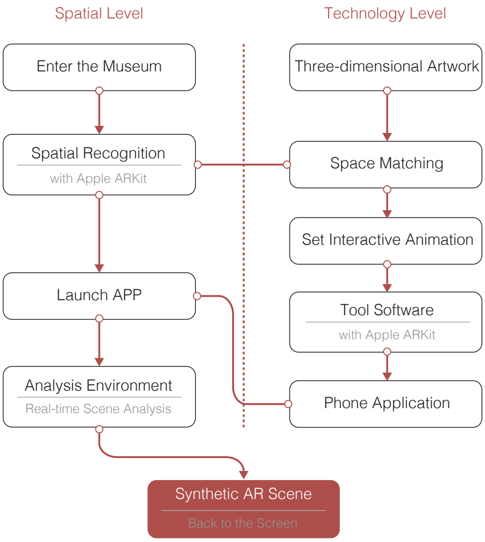
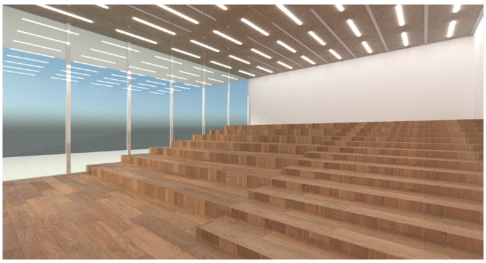
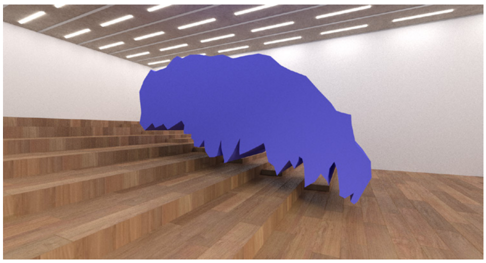


Fig.5.64: Spatial level and tech. level work flow in this case
Source: Made by Author

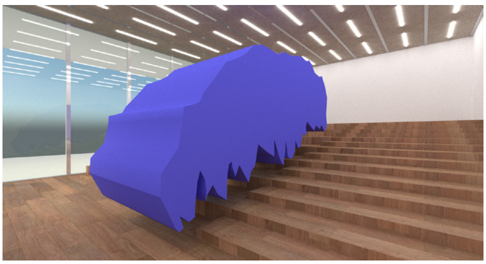
- Experience:
The audiences of modern art museums are often very receptive to new technologies. This has also changed the way users experience and interact in the museum space. The ingenious integration of AR artworks and museum space constitutes a new field worth exploring. Augmented exhibits that cannot be observed by the naked eye are "hidden" in architectural space. Visitors re-observe, re-experience and re-understand the open space where they have been neglected. With AR exhibits, original architectural space has been enhanced and re-developed; visitors will also have a deeper understanding of artworks. As shown in Fig.5.65, visitors in different positions can have different perspective images of exhibits through devices. Although experiencing AR artworks through handheld devices limits the size of its representation. But we can understand the device as another form of



Original Space: Place A View without AR



Augmented Space: Place B view



Augmented Space: Place A view

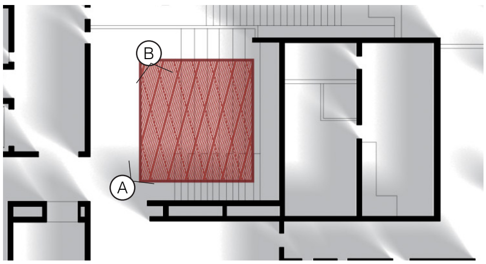


Fig.5.65: Original space and augmented space in different views
Source: Made by author

a picture frame. By moving the frames, visitors can see different content, which also encourages visitors to explore in disguise and interpret the experience of virtual art in real space from a different perspective. It is foreseeable that in the future, this frame may evolve into many forms or even disappear entirely (with the help of glasses and other equipment). AR is no longer discussed as an emerging technology, but art and architectural medium. At that time, we can expect more immersive works of art to change our perception of existing spaces and art.

Feedback

Funding and guidance from the Knight Foundation[1] is an essential factor in promoting this project. This also depends on the foundation's attitude towards future art and technology: they hope to better help museums meet the needs of the community and participate more in art-related experiences and dialogues through new digital media. Victoria Rogers, vice president of the foundation, said: *"People want their art experiences to be personalized interactive and shareable, just as they expect of everything else in their daily lives."*

1.The John S. and James L. Knight Foundation is an American non-profit foundation dedicated to fostering "informed and engaged communities" which the foundation believes are "essential for a healthy democracy." The foundation "supports ideas that promote quality journalism, advance media innovation, engage communities and foster the arts."

The results of "Invasive Species" have also met the expectations of all parties. As the museum's first AR art exhibition, local media and art institutions praised it, and visitors are also willing to use mobile phones or tablets to participate in the augmented experience with a positive response. "Interesting" and "amazing" are the most common comments from the audience about the project. However, as a new form of artwork, it will also be criticized by art critics, such as the authenticity of the digital environment and the nature of artistic experience. As much as Augmented Reality and other new technology tools give artists frontiers for aesthetic representation, they also provide platform doubters who are afraid of new technologies. This critical argument often appears when new visual technologies, such as cameras and films, emerge. Faced with this challenge, the director of the museum said: *"As a 21st-century museum, PAMM seeks to reinforce the idea of the museum as a place for experimentation and a laboratory for ideas, [...]to enable visitors of all ages and backgrounds and to interact with the most progressive visual arts of our time."*

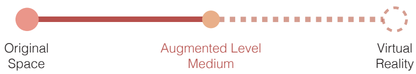
References

1. PAMM, "Augmented Reality (AR) Exhibition" Accessed August 19, 2020, https://www.pamm.org/ar

2. Claudia Malfitano, "Interviews Felice Grodin Presents Miami's 'Invasive Species'", Accessed August 19, 2020, https://myartguides.com/interviews/felice-grodin-presents-miamis-invasive-species/

3. Solko, David. *Evaluating Enhanced Reality Interfaces and the Museum Experience*. Diss. University of Cincinnati, 2018.

Fig.5.66: “SmartGuide in Casa Batlló” Experience interior, 2015, Casa Batlló, Spain



Case6: SmartGuide in Casa Batlló

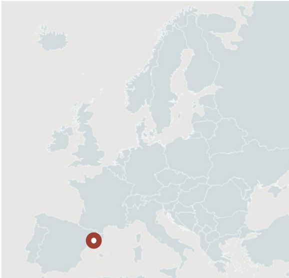


Fig.5.67: Casa Batlló Position

Casa Batlló Museum

Design Team: Universitat de València
Barcelona, Spain
2015

Fig.5.68: Casa Batlló Photo

Museum Type: Site Museum
Tech. Type: Augmented Reality + Interactive
Tech. Devices: SmartPhone
Tech. Support: ARTEC

Introduction

Casa Batlló is a building designed by the Catalan modernism architect Antoni Gaudí, located in the centre of Barcelona. With its fantastic shapes and rich colours, Casa Batlló has become the most dreamy work in all of Gaudi's buildings. Among Gaudí's architectural works, Casa Batlló is one of two buildings with the theme of ocean and water. The design of Casa Batlló from the exterior to the interior details is like the mysterious underwater world in Gaudí's dream. In this design, Gaudí seems to actively avoid the use of straight lines, instead of using rhythmic and poetic curves to show the entire architectural space. The rich architectural details, colours and materials make the entire building from the external facade to the internal space, and even the furniture components shine with exciting brilliance. This magnificent building was officially opened to the public in 2002, transforming rom a private real estate into the Casa Batlló Museum, and achieved unexpected success. Casa Batlló received about 3000 visitors per day since it opened to the public. And In 2005, Casa Batllo officially became a UNESCO World Heritage Site.

SmartGuide tour is one of the projects prepared at the beginning of the museum. It aims to help users better participate in the visiting process, and show visitors the design, aesthetics and history of this architectural site. Since 2015, the University of Valencia (Universitat de València) has participated in the design process of the smart guide and introduced augmented reality technology. With the help of advanced virtual vision technology, users can not only see the original furnishings of Casa Batlló (most of the furniture has

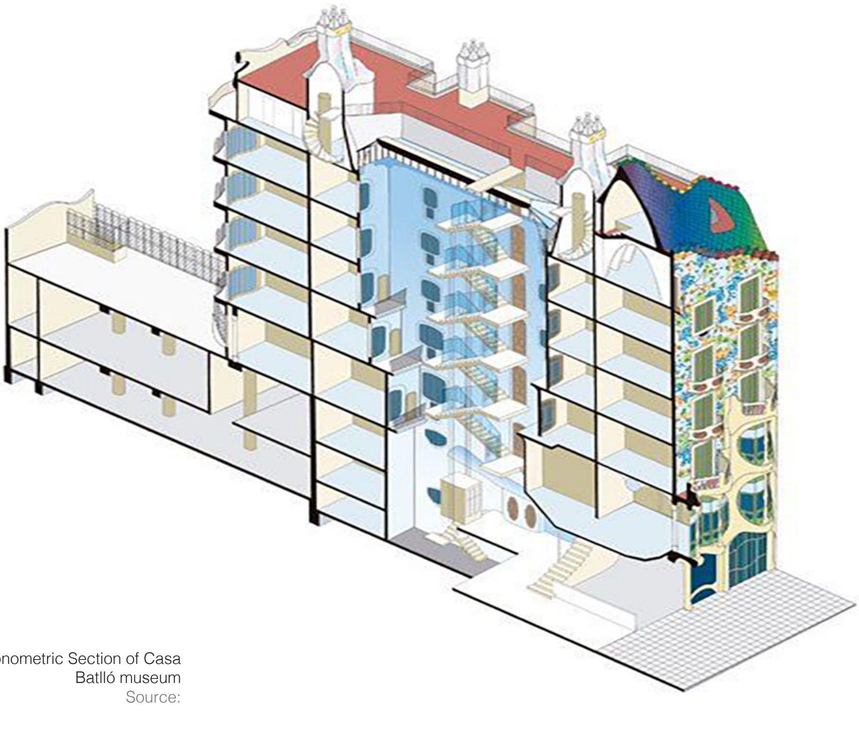


Fig.5.69: Axonometric Section of Casa Batlló museum
Source:

been removed due to visit requirements) and the interior space but also understand the source of inspiration for many design details through the video (as shown in Fig.5.70).

Fig.5.70: Skylight design inspiration, Casa Batlló augmented video guide
Source: https://www.alphr.com/apple/1001182/shake-up-the-gallery-how-ipads-are-changing-the-way-we-visit-museums

Concept

- Inspiration:

With the increasing number of tourists visiting, Casa Batlló Museum is always looking for ways to improve the user experience for tourists during the visit. At the beginning of the opening of the museum, the audio-guide which is widely used in many different museums for visitors. They can hear a detailed introduction through headphones. However, it is difficult for audio and textual information to accurately show the original environment and design inspiration or details of the building to visitors. In other words, audio and text information is less convincing and attractive than graphic information that is fused with the surrounding content. Therefore, the museum needs to develop new visual technology for the learning and dissemination of cultural heritage and provide users with a new method of art appreciation. AR is the best feasible tool considered by the museum. In view of the increasing maturity of AR technology and its successful application in certain heritage museums, AR could be seen as the best feasible tool for site museums. In order to give visitors more space and protect the furniture, the museum had already removed most of the indoor furniture when it opened (as shown in Fig.5.71). The museum hopes to re-display the moved furniture to visitors through virtual technology. In their vision, it would provide users with a sense of immersion where history and reality are intertwined.

Fig.5.71: Comparison of history and status quo, Up: Salón principal de los Batlló in 1927, Down: Salón principal de los Batlló in 2006
Source: https://es.wikipedia.org/wiki/Casa_Batll%C3%B3

- Strategy:

AR technology has been applied in some museums

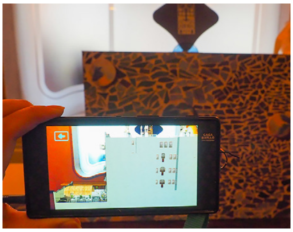


Fig.5.72: AR Experience in Casa Batlló Museum
Source: https://haruhii.pixnet.net/blog/post/

Fig.5.73: Wrong occlusion relationship between virtual objects and people in screen.
Source: https://haruhii.pixnet.net/blog/post/

before the project was launched. For example, scanning a QR code (or a specific object) provided by the museum will generate some real-time rendered 3D models combined with the physical space on the mobile phone screen. Although this type of AR experience is also used in Casa Batlló Museum (as in Fig.5.72: when using a mobile phone to scan a physical architectural model, the section 3D model will be displayed on the mobile phone screen), this similar traditional AR solution faces many difficulties and challenges in many scenes and rooms in the Casa Batlló Museum. Firstly, the small space and a large number of tourists limit the ability of traditional AR to identify existing spaces. Under normal circumstances, traditional AR needs to locate and generate virtual models through some characteristic objects (the most common is QRcode). The interior space of each room is not large, and at the same time, it has to accommodate many tourists to visit together, which causes the mobile phone camera to be unable to accurately find the objects that need to be identified. Secondly, Limited by the computing power of mobile phone processors, traditional AR cannot form a correct occlusion relationship between virtual three-dimensional objects and other viewers in real space. The uncorrect occlusion relationship (shown in Fig.5.73) will seriously damage the immersion brought by virtual vision technology. Thirdly, The technical means at that time could not provide a high-resolution 3D model that matched the real world, which would also split the boundary between virtual and real. At the same time, limited by the various lighting effects of the museum interior space, the user experience of traditional AR used in Casa Batlló is not good. Based on the above reasons, the design group tried to develop a new type of AR named indirect AR to propose a solution using virtual vision technology in a crowded and narrow space.

- Project:
Compared with traditional AR, indirect AR does not need to rely on real-time graphics information in the real space, which avoids the impact of lighting and crowds on the real space. In order to represent a high-quality virtual space and respond to the aforementioned condition, the team at the Universitat de València built an augmented cube to simulate the real environment. The panoramic picture synthesized from more than 40 photos was transformed into a six-sided cube model by technical means. This augmented cube is equivalent to the real background space of traditional AR. And the height of the viewing (camera height) is defined as 1.6 meters from the floor, which similar to the height of sightline in reality. After determining the background information, the design team began to prepare the virtual exhibits, including high-precision 3D furniture models based on detailed research of historical data. In addition to static 3D contents, the design team also introduced dynamic three-dimensional information, animated virtual models and video effects. They want to use these dynamic 3D contents which are related to the background augmented cube to explain some architectural details inspiration and stories. For example, when people using SmartGuide in a specific room, they can see an interesting animation that a dynamic mushroom appears in the fireplace through phone screen (as shown in Fig.5.74). The production team will one-to-one correspondence between the virtual model and augmented cube and integrate them into the program. In the latest version of the application, the user's location and the room will be judged by Bluetooth technology, and the correct augmented cube will be displayed to the user.

Fig.5.74: Mushroon animation for the fireplace in Augmented Reality
Source: https://es.wikipedia.org/wiki/Casa_Batll%C3%B3

- Relationship:

The project is led and developed by the Casa Batlló Museum. The Universitat de València has made many contributions in technology and design, especially their pioneering indirect AR technology. This technological innovation solves many difficulties in using AR in museums. The interesting relationship change lies in the space between the user and the augmented reality. In traditional AR projects, the real world space displayed on the user's mobile phone screen as a background layer, and the user needs to explore virtual objects through the augmented space on the screen. On the contrary, indirect AR displays a preset augmented cube on the mobile phone, and the user needs to find the corresponding position in the real world space according to the guidance. The furniture with historical significance is loaded in the augmented cube through the virtual form, and the visitors stand in the "real cube(space)". This kind of experience and relationship is interesting and subtle.

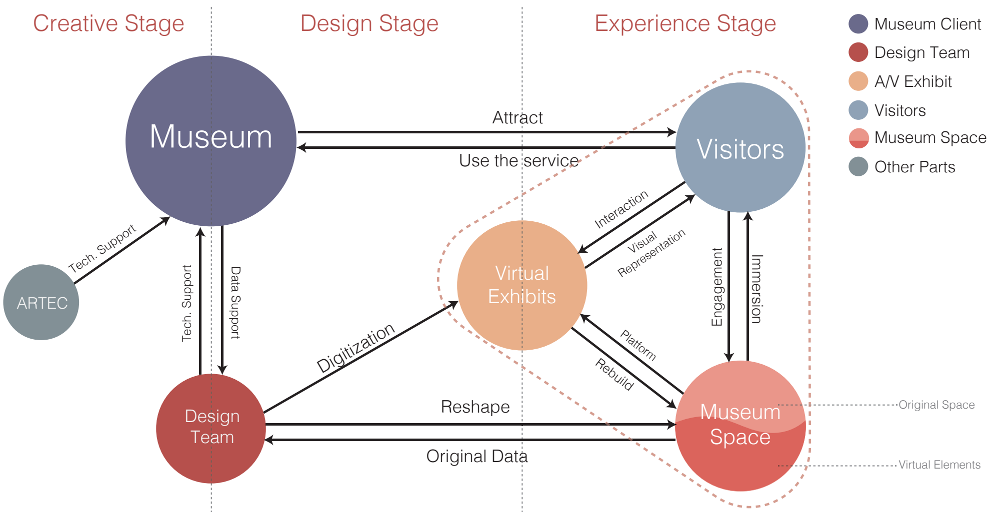


Fig.5.75: Relationship Diagram in "Invasive Species"
Source: Made by Author

Analysis

- Space:

The architectural space in the project is not only the original data forming the augmented cube, but also the "cube" that carries the virtual contents. According to the different virtual exhibits, from a spatial perspective, the architectural changes brought by augmented reality can be understood from two aspects. On the one hand, it refers to the in-depth digital restoration of historical heritage. In this case, the original space of the museum will be restored to what it was decades ago under the effect of digitalization. Visitors will experience both the present and the past in the real space. This augmented space is a rare form of space for cultural heritage with historical significance. On the other hand, the design team used some animation settings to make the augmented space not only the original space as the background layer but also the primary platform of the advanced dynamic space. This mode of space is different from the static space under the traditional cognitive system. The elements in the

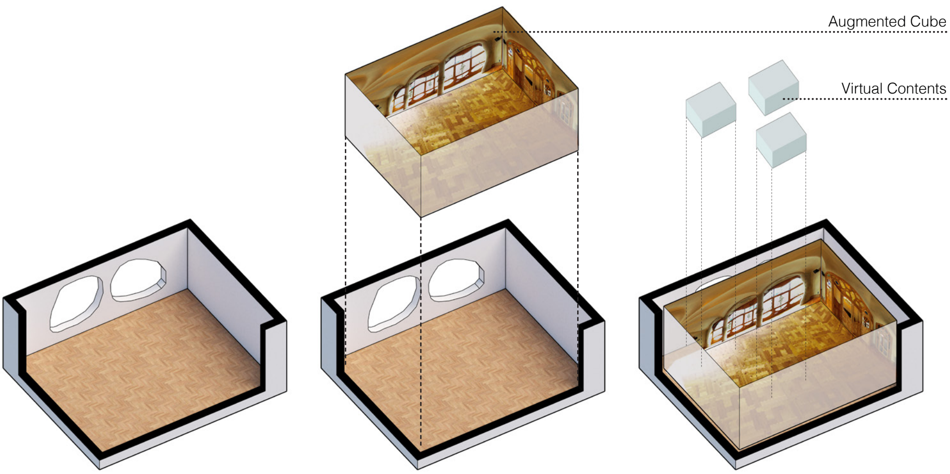


Fig.5.76: Axonometric Diagram of Augmented Cube
Source: Made by author

space can transcend physical limitations and transform into dynamic three-dimensional animations. In other words, this dynamic element activates the original space and make the original space develop a new digital form.

- Technology:

The use of innovative AR technology makes the project shine in cultural heritage museums. From a technical point of view, indirect AR can be said to be a combination of AR and VR. VR is a virtual visual environment constructed entirely of digital information, constructed through panoramic images or scenes. AR refers to the real space as the background layer and the addition of digital information that conforms to the real-world interaction logic overlay it. The project

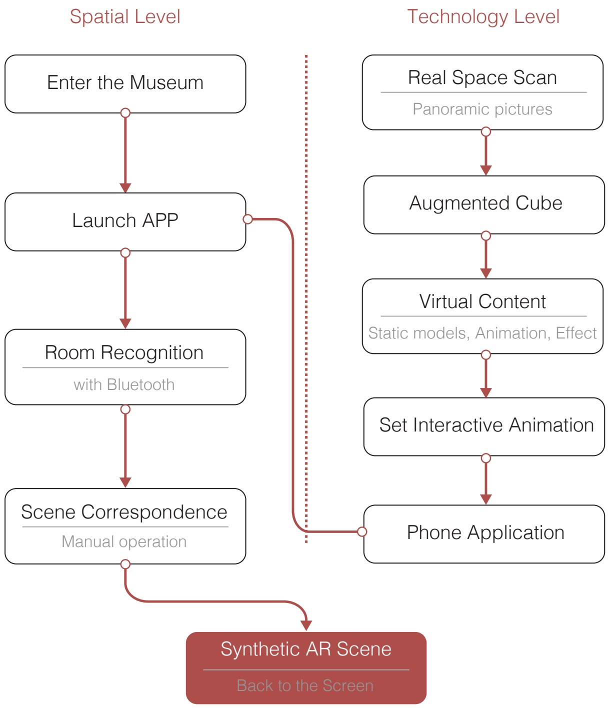
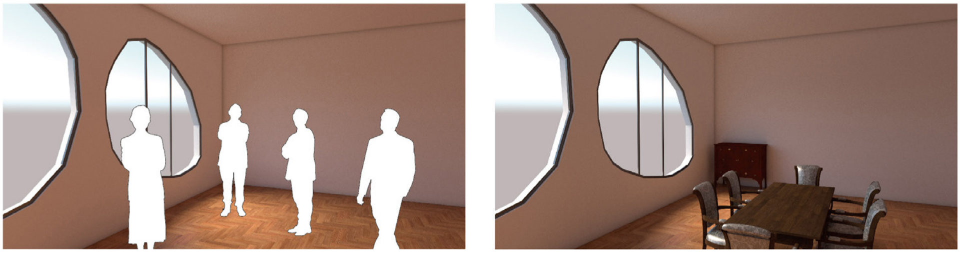


Fig.5.77: Spatial level and tech. level work flow in this case
Source: Made by Author

combines the two technologies: obtain the image information of the real space through the camera, and convert it into a VR panorama picture, and then use the VR panorama picture as the background. Based on the background of the VR panoramic image, add the corresponding space of augmented elements (furniture models and 3D animation in this case). Indirect AR technology solves the difficult problem of accurately capturing the scene space in the narrow space of the museum through preset background pictures, and represents the relationship between virtual and real space as much as possible. It not only guarantees the authenticity of architectural space and experience but also provides cutting-edge visual technology in the digital age.

- Experience:
For tourists who participate in the experience in the site museum, they not only want to see the current situation of the heritage but also hope to feel the glamour and aura (Benjamin, 1935) brought by the cultural heritage through the introduction and exhibition of the museum. This contrast and change between reality current and past are difficult to represent through traditional media such as images and videos. The introduction of AR technology is part of the SmartGuide tour in this project, which means that when users enter the museum, they can get the device and learn how to use it. The simple use of the program also improves the user experience, allowing users to focus more on the virtual exhibits on the phone screen. With the update of the application, visitors can automatically trigger the augmented space in the corresponding room. This user-friendly trigger method will also be loved and tried repeatedly by visitors. According to the museum's data and survey, visitors showed a different interest in the form of augmented animation from other exhibitions.

Visitors stayed the most time in the room with the animation presentation. Many visitors even watched the animation two to three times. It is enough to show that users admire augmented exhibits and interactive spaces.



Real Space Scenes

Augmented Scenes in Screen

Fig.5.78: Original space and augmented space in different views
Source: Made by author

Feedback

The museum collected users' opinions and feedback after using the smart guide. Based on this survey, the interviewed audience showed a positive and exciting attitude towards the application of augmented reality. Many people are most interested in seeing furniture that does not exist in the original space. Users also mentioned a few bad experiences such as equipment and interface operations during use. Another unfriendly way for visitors to enjoy indirect AR is that visitors need to find the corresponding content in the real space through the scenes represented on the mobile phone, which reduces the immersion brought by virtual technology in the initial stage of touring. In addition to the visitors, the media and society also reported and evaluated the project. On the one hand, it is based on the cultural heritage value and artistic achievements of Casa Batlló itself; on the other hand, it is the collision and impact of cutting-edge visual technology and traditional art and culture. And AR integrates the two ingeniously and creates a new experience. Casa

Batlló's team also hopes to use modern technology to reshape the spirit of space given by the great architect Gaudi.

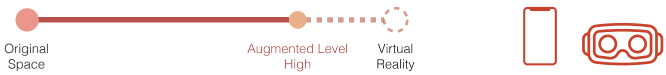
References

1. Gimeno, Jesús, et al. "Combining traditional and indirect augmented reality for indoor crowded environments. A case study on the Casa Batlló museum." Computers & graphics 69 (2017): 92-103.

2. Martínez, Bibiana, et al. "TinajAR: an edutainment augmented reality mirror for the dissemination and reinterpretation of cultural heritage." Multimodal Technologies and Interaction 2.2 (2018): 33.

3. Casa Batlló museum offical website, Accessed August 25, 2020, https://www.casabatllo.es/

Fig.5.79: “Rhomaleosaurus: Back to life in virtual” Experience Scene in Glass, 2016, The Nature History Museum, London, UK



Case7: Rhomaleosaurus: Back to Life in Virtual Reality

The Nature History Museum

Design Team: Framestore
London, UK
2016

Museum Type: Nature and History Museum
Tech. Type: Static Virtual Reality
Tech. Devices: Smartphone + Google Cardboard
Tech. Support: Google Creative Lab
Agency: Google Creative Lab

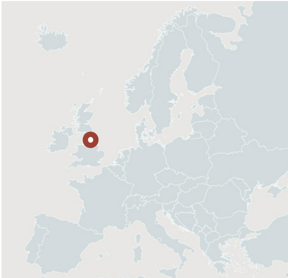


Fig.5.80: The Nature History Musuem Position

Fig.5.81: The Nature History Musuem Building Photo

Introduction

"Rhomalesaurus: back to life in virtual reality" is a new experience uses the bones of a sea dragon to recreate life in virtual Jurassic under-water-world through virtual reality tecnology. This project is one part of the Nature History Museum (London), which is a museum that exhibits a vast range of specimens from various segments of natural history. The museum has many fossils and related materials of paleontology, and these exhibits had always been in the glass window for visitors to inspect and learn. The emergence of virtual technology has changed the way of exhibition for a long time. When visitors put on VR glasses, they will find a realistic and immersive scene: the Rhomaleosaurus at the Natural History Museum, a Jurassic marine reptile which breaks away from its replica display to swim through a freshly submerged Marine Reptile Hall where they standed on few minutes ago.

This project is created by Google Creative Lab and designed by Framestore. Framestore is a British animation and visual effects company based on Chancery Lane in London. Formed in 1986, it acquired (and subsequently merged) the Computer Film Company in 1997. The company works across several different areas of the media: feature films, commercials, music videos, feature animation and digital. Framestore has a proud history creating extraordinary images and scenes for some of Hollywood's biggest pictures, collecting every possible industry award along the way. At the same time, this company The company

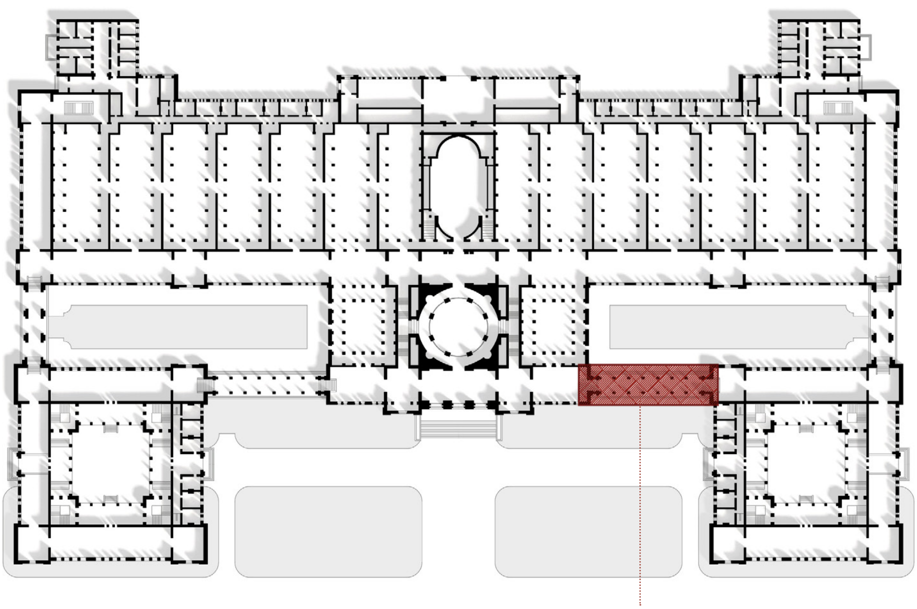


Fig.5.82: Plan of Nature History Museum
Source: drawn by author

also has a lot of involvement in immersive experience and display projects, such as *"Beyond the Walls"* in Smithsonian American Art Museum (Fig.5.83) and *"Visit Britain AR game"* with Birtish Airways (Fig.5.84).

Fig.5.83: “Beyond the Walls” Users in virtual experience, 2019, Smithsonian American Art Museum

Fig.5.84: “Visit Britain AR Game” Users in experience, 2019, British Airways

Concept

- Inspiration:

This project was initiated by Google, aimed to create a way for people to discover Natural History on Google's Arts & Culture platform. Facing the challenges of new technologies, they decided to create "Back to Life in Virtual Reality", working with Natural History Museum in London. Working closely with Google‘s experts and using Google’s proprietary technologies in the process, Framestore worked to weave an engaging and immersive tale of extinction illustrated by extremely rare prehistoric specie. Users can come face to face with extinct animals and see how our actions impact species today-giving people a new way to experience the past and motivating them to help preserve life on our planet for the future. Similar to many digital artworks, although this virtual experience can be obtained through VR glasses anywhere, watching this creative artwork in the museum with the authenticity of space can bring the most shocking experience to the visitors.

- Strategy:

After determining the basic concepts and setting ideas, Framestore’s creative technologists, developers and artists formed a team with ecologists, paleontologists and biologists from the museums and Google’s in-house experts. Unlike many VR experiences which transport audiences to an entirely new setting within the headset, the Natural History Museum experience sees the creatures come to life within perfectly executed, high resolution recreations of the London venues. This

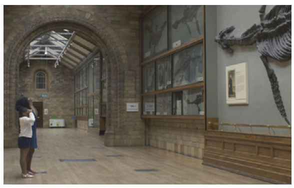


Fig.5.85: “Rhomaleosaurus: Back to life in virtual” Users in Museum, 2016, The Nature History Museum, London, UK

means that the state of the museum's original space can still be seen in the virtual environment, and the new underwater environment and interactive paleontology generated by artistic creation can be understood as an additional digital information attached to the original museum space. From this perspective, the project can also be understood as an augmented reality project rather than complete virtual reality. The virtual environment that is separated from the real space cannot deeply arouse the user's sense of identity and immersion in the use of space. This is where the project differs from other fully virtual environment projects in other museums. Authenticity and scientific were the keys of these project. How to make visitors truly immersed in the virtual environment requires high-precision restoration and creative reconstruction of the original environment. In Framestore's words, it called "facts-over- fiction" approach. As Karl Woolley, Head of VR at Framestore, said: *"Often with virtual reality we're looking for the thrill factor, and really push our creative licence to achieve it. In this instance, that same thrill is in the accuracy. Every element of the creatures was thoroughly fact-checked, and by the greatest authorities on the species in the world. I would anticipate that these are the most accurate graphical representations of these creatures ever made."*

Fig.5.86: Reconstruction of museum space in digtial mode

- Project:
In order to restore the museum space in the virtual environment with high precision, the team used laser scanning to capture the museum building. The museum is reshaped by the designer and fill the entire exhibition hall with the underwater world. Respect of museum orginal space is essential for the final rendering effect which brings the immersive experience to the visitors. Virtual exhibits, marine organisms, also plays a vital role in this project. Framestore had very rich experience in this area, having won multiple awards for the BBC's Walking with Dinosaurs series in 1999. Nevertheless, they still put a lot of effort on the creatures' movements, using a custom muscle and flesh skin system built specifically for the job. A team of three texture artists then spent a month perfecting the exterior look and feel of the creatures' skins. Framestore's Design Studio provided the photo cards which, along with the voiceover, give audiences detailed information on both the star creatures and the context of their extinction.

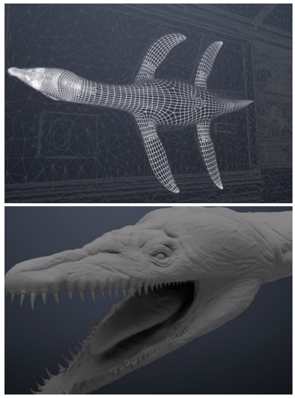


Fig.5.87: Restoration of space and creation of details of virtual objects

The outcomes are suitably epic, bringing important tales of extinction to audiences around the globe. *"Virtual reality has incredible immersive power",* said Woolley. *"In this instance, using it to educate as well as entertain has been extremely rewarding. Google Arts & Culture has a huge manifesto, to bring cultural institutions alive to those unable to visit in person, and Framestore are pleased to play a part in that mission".*

-Relationship:
Designers play a complex role in this project, not only with the creative side (Google Art & Culture), but also with museums and experts in various related fields to complete this virtual experience project. From the perspective of museum space, the complexity of

this relationship has completed a new transformation due to the interaction between the audience and the exhibits. The relationship network can be summarized as shown below:

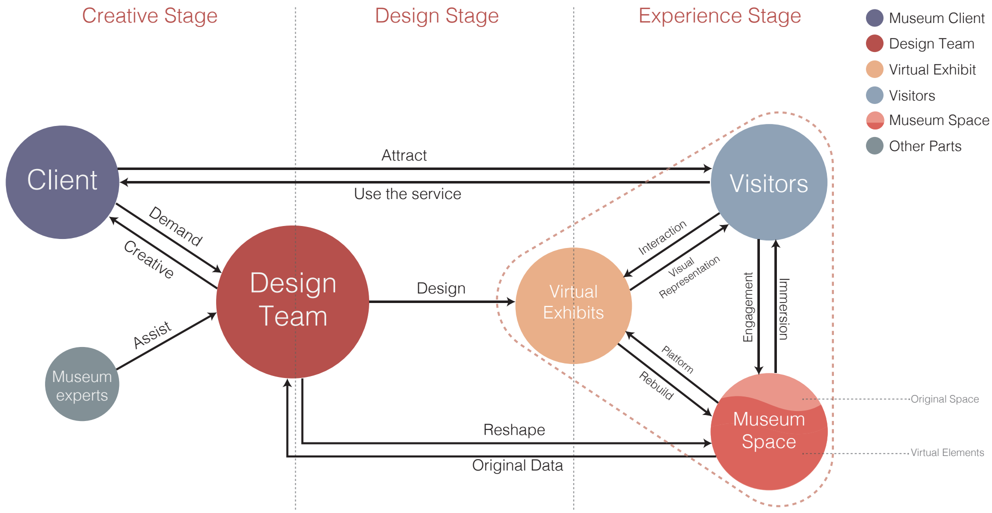


Fig.5.88: Relationship Diagram in "Back to life in virtual reality"
Source: Made by author

Analysis

-Space:

Respect of museum orginal space is essential for the final rendering effect which brings the immersive experience to the visitors. The architectual space has completely evolved into a new form under the influence of virtual technology. In this project, the building space was transformed into an "impossible" space by the designer. Based on the virtual experience, immersion and interaction of the virtual (augmented) exhibition, architects and designers can no longer stick to the constraints of material and mechanics. The artistry of the space and the creativity of the architect can be displayed more unlimitedly. Under normal circumstances, we cannot create a museum in an underwater environment, and even visitors roam in the exhibition hall filled with water. This space change experience is not completed in an instant, in the virtual space demonstration. The exhibition hall gradually changed from the real state to the underwater form, and the fossils on the wall slowly "revived" with this change. This process of gradually changing the environment where the user is actually into the "impossible" space is also worthwhile thinking. If the user puts on VR glasses and directly presents an underwater world, such a spatial change experience is not intuitive.

Fig.5.89: Different Experience from Original Space and Virtual Space

-Technology：

From a technical point of view, the project attempts to use virtual reality technology to reproduce the underwater world in ancient times, and this underwater world is not a completely independent and completely new space, but is restored based on the real scene of the Natural History Museum. Requires accurate

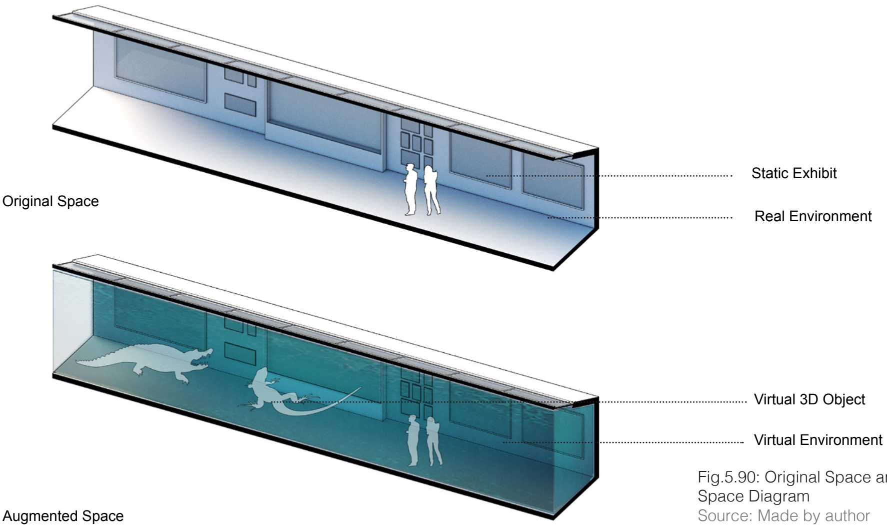


Fig.5.90: Original Space and Virtual Space Diagram
Source: Made by author

scanning and reconstruction of the original space. On this basis, the animation effect of gradually changing marine life from fossils and bones into real living bodies, supplemented by changes in sound and light and shadow, together constitute a complete virtual environment. In the end, these virtual environments were transformed into immersive 360° VR videos through panoramic rendering, and presented to visitors via smartphones and VR glasses (Fig.5.91).

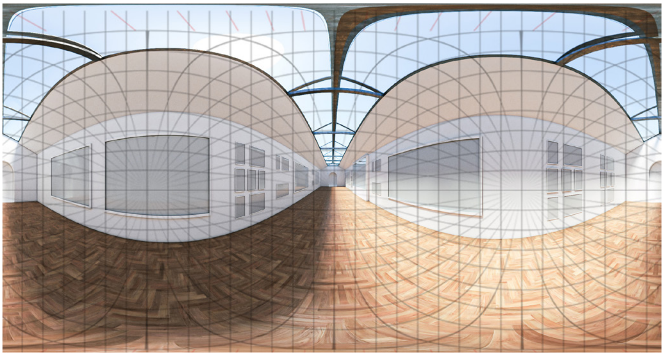


Fig.5.91: Museum space in VR panoramic view
Source: Made by Author

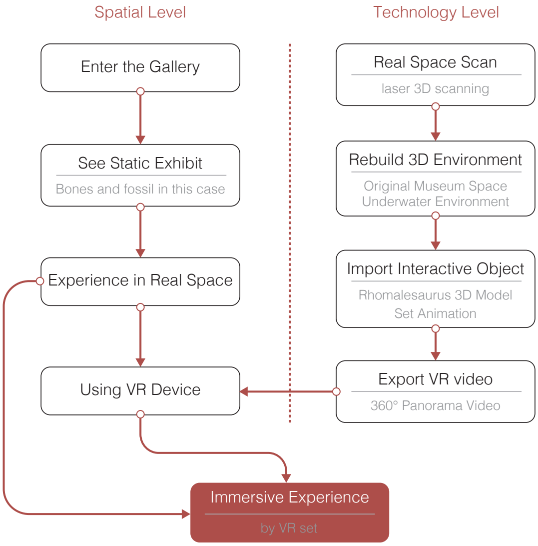


Fig.5.92: Spatial level and tech. level work flow in this case
Source: Made by Author

- Experience:

The user experience can be said to be shocking and subversive in this project, It is different from the static exhibition mode of traditional museums, The virtual reality combined with the real physical space can bring more immersive experience depth to the audience than the completely virtual environment. As Prof. Paul Barret[1] said: *" It is an amaing experience to see the life reconstruction of these animals within the space where their skeletons are also kept. I am used to walking through the museum at different times of day, seeing the skeletons on the wall, but I have never seen a living marine reptile. Seeing one of these actually come off the wall give a real new dimension*

1. Paul Barret is merit researcher in Natural History Museum, centred on the evolutionary palaeobiology of dinosaurs and other extinct amniotes.

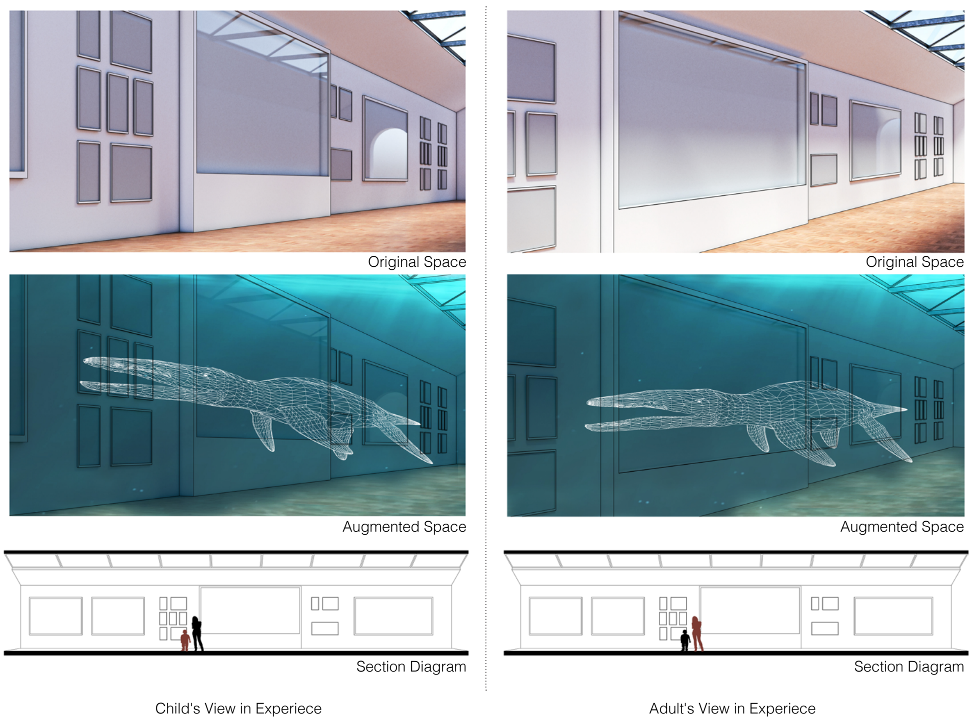


Fig.5.93: Original space and augmented space in different users
Source: Made by Author

to how we appreciate those animals." This change in space experience is also very attractive to one of the main user groups of the Natural History Museum, young children. During the exhibition, visitors can often hear the voice of “Wow” by children during the Virtual experience. This kind of augmented exhibition is helping to catch people's attention, Understanding the life status of extinct creatures in an augmented space can better awaken their new understanding of ecology. This is also an important reason for choosing virtual experience in the museum which is combining fun, interest and science and technology together to show its visitors.

Feedback

The project was completed in 2016. In 2016, VR and AR were very novel and cutting-edge topics. Users have great curiosity and participation in virtual vision technology. Coupled with Framestore as a leader in the field of computer graphics represetation, the completion of the project has attracted many media reports(as shown in Fig.5.94). The media expressed surprise and approval for the project. Such as *" bridge between culture and technologies like VR" (Wired culture)* and *"incredible virtual tours of museum" (Mail online).* From the data, the project is still successful,

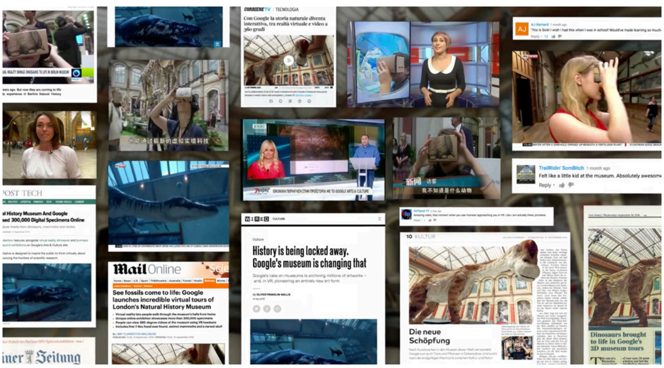


Fig.5.94: Many media reports on this project

according to incomplete statistics: more than 1.2M people have tried the experiences with 250M+ social impressions.

Virtual vision technology is changing our way of life and our understanding of the meaning of space, Dr Milner has witnessed many changes in the Museum's collections over the decades, and she said: *"Virtual reality technology demonstrates how much we have learnt, and this project also highlights the threat of extinction many species are facing. It is the role of the Museum to make people aware of how some species are suffering. Any tool we can use to do that is a positive one, and virtual reality can help us to reach new audiences."*

References

1. Framestore. "Natural History Museums." Accessed June 19, 2020, https://www.framestore.com/work/natural-history-museums?language=en

2. García, Adolfo Muñoz, and Ana Martí Testón. 2018 "Reframing museum experiences with augmented reality to transform museums content into an emotional journey." In *10th International Conference on Education and New Learning Technology (Palma, 2nd-4th of July, 2018):* conference proceedings. IATED Academy, 2018.

3. K. Pavid. "How to resurrect a sea dragon." Accessed June 19, 2020, http://www.nhm.ac.uk/discover/how-to-resurrect-a-sea-dragon.html

5.3 Other Cases

The rapid growth and popularity of virtual vision technology have led museums worldwide to experiment with AR and VR, whether for the purpose of obsessing over new technology or engaging potential audiences. In addition to the seven detailed case studies mentioned above, there are still many interesting and worthwhile cases that need to be described and explored more. In this section, the authors will select more types of museums and exhibition spaces that apply different virtual vision technologies. Through a brief introduction to their design and experience, it is possible to understand why and how designers and curators consider using these visual technologies in museum spaces and explaining the differences between the original spaces and the augmented spaces.

A series of brief case studies illustrating the current state and future of virtual vision technology in museums at a quantitative level, these cases and data reveal museums' decisiveness and enthusiasm to use new technologies. Augmented exhibits work in conjunction with visitor behaviour in real museum spaces to form virtual experiences. These cases present unique augmented exhibits and virtual experiences through their different technical means and different museum spaces. Through these museum spaces enhanced by virtual visual technologies, real museums' meaning and future development under virtual technologies can be more critically discussed. And based on the relevance and comparison of these cases, the significance of new technologies for the future exhibition space is explored inspirational.

Other Cases List:
1. "Invisible Museum", *Consumer Electronics Show 2016*, USA, 2015
2. "ReBlink", *Art Gallery of Ontario*, Canada, 2017
3. "Lumin", *Detroit Institute of Arts*, USA, 2015
4, "[AR]T in Partnership with Apple", *New Museum of Contemporary Art,* USA, 2019
5, "Mauritshuis HoloLens", *Mauritshuis (Maurice House)*, Netherland, 2019
6, "Augmented Reality Tour", *Morgan Library & Museum*, USA, 2019
7, "Dambusters Raid with VR", *Royal Air Force Museum*, UK, 2019
8, "Art VR", *Tretyakov Gallery*, Russia, 2018
9, "Unexpected Growth", *Whitney Museum of American Art*, USA, 2019
10, "Bring Dinosaurs to Life", *Museo delle Scienze (MUSE)*, Italy, 2018
11, "Mont-Saint-Michel HoloLens", *Musée des Plans-Reliefs*, France, 2018
12, "Plaster ReCast", *Carnegie Museum of Art*, USA, 2017
13, "Concrete Storm", *The Armory Show*, USA, 2017
14, "Into the Wild", *ArtScience Museum*, Singapore, 2018
15, "Thresholds", *National Science and Media Museum*, UK, 2018
16, "Changdeok ARiring", *Changdeokgung Palace*, South Korea, 2020

Invisible Museum

Fig.5.95: CES2016 Exhibition Position

Fig.5.96: Invisible Museum Photo

Consumer Electronics Show 2016

Design Team: Qualcomm

Las Vegas, USA

2015

Museum Type: Science and Technology Exhibition

Tech. Type: Augmented Reality + Interactive

Tech. Devices: Sony Xperia Z4 tablet

Introduction

Invisible museum is is an attempt by the Qualcomm® to apply augmented reality in the field of exhibitions during CES(Consumer Electronics Show)2016. In this small exhibition, The floor and walls and the six pedestals are all pure white, but no exhibits and brands can be found in the real space. Visitors can discover virtual exhibits by AR technology through tablets. The exhibits include Qualcomm®'s contributions to smart cities, Internet of Things, photography, robotics, and mobile experience.

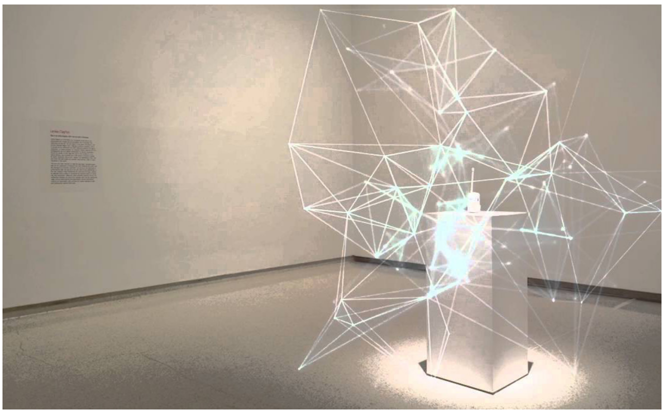


Fig.5.97: Invisible Museum Exhibits in Screen

ReBlink

Art Gallery of Ontario

Design Team: Impossible Things
Toronto, Canada
2017

Museum Type: Art Museum
Tech. Type: Augmented Reality + Interactive
Tech. Devices: SmartPhone and Tablet

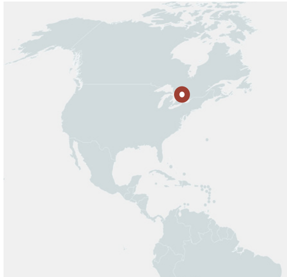


Fig.5.98: Art Gallery of Ontario Position

Introduction

ReBlink is an exhibition that made re-interpretation and re-creation of traditional art works in the Art Gallery of Ontario through AR technology. Classic works of art have been given new meanings in the digital age. This is not only from the way of representation, but the recasting works of art also capture the profound themes of modern society. Visitors in the museum can feel the interweaving and impact of the past and modern elements through their mobile phones. This novel experience is unexpected and worth looking forward to.

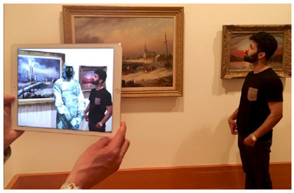


Fig.5.99: Art Gallery of Ontario Photo

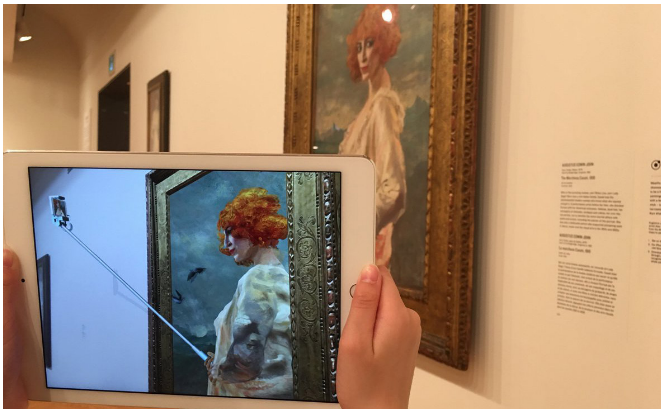


Fig.5.100: Visitor is viewing the Reblink through tablet

Lumin

Fig.5.101: Detroit Institute of Arts Position

Detroit Institute of Arts

Design Team: GuidiGo

Detroit, USA

2015

Museum Type: Art Musuem

Tech. Type: Augmented Reality + Interactive

Tech. Devices: SmartPhone

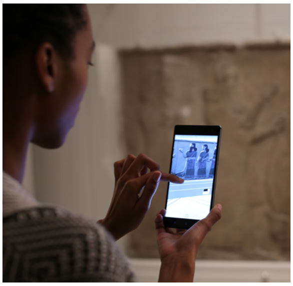


Fig.5.102: Detroit Institute of Arts Photo

Introduction

The Detroit Institute of Arts premiered an augmented exhibition named Lumin which developed by GuidiGo through Google Tango technology in 2015. Through novel interactive methods, users can observe additional content beyond the original exhibits through smartphones. For example, users can use a mobile program to see the bones inside the mummy, just like using X-rays (Fig.5.103). For some exhibits, AR technology can also restore the original appearance and color of the artwork on the visitors' screen.

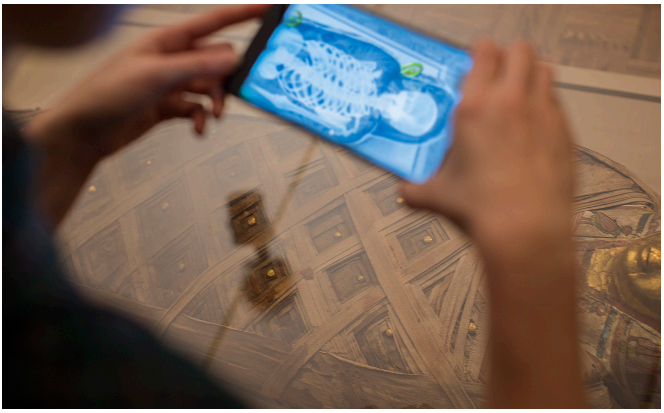


Fig.5.103: Users are using mobile phone experience to augmented exhibits in the Lumin project

[AR]T in Partnership with Apple

New Museum of Contemporary Art
Design Team: Apple
New York, USA
2019

Museum Type: Art Museum
Tech. Type: Augmented Reality + Interactive
Tech. Devices: iPhone

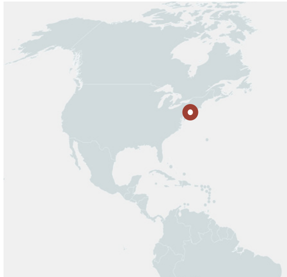


Fig.5.104: New Museum of Contemporary Art Position

Introduction

[AR]T is a new augmented reality initiative collaborated with Apple, to create a series of art works through advanced AR technology. The museum invited a distinguished group of artists to produce different art pieces. With the help of the characteristics of AR, the designed artwork can be naturally generated in the real space. The combination of virtual artwork and real environment brings a new unique experience of AR artwork. This interactive artwork raises the possibility and exploratory of this new art type based on the real environment and space.

Fig.5.105: AR artwork experience in screen

Fig.5.106: AR artwork experience in screen

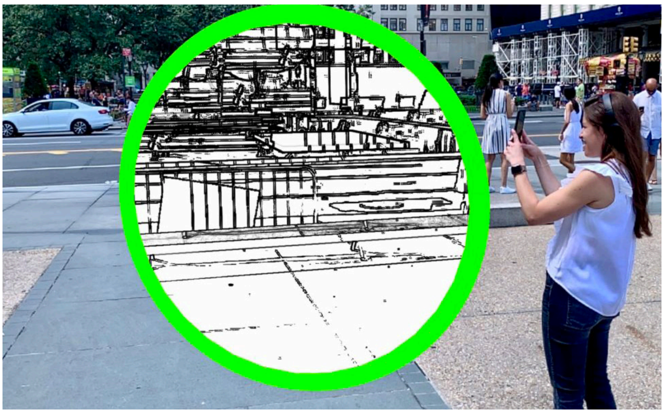


Fig.5.107: Visitor is viewing the Artwork through Phone

Mauritshuis HoloLens

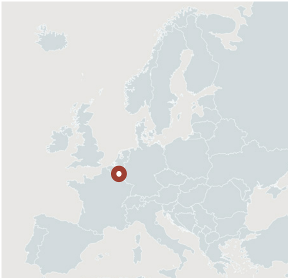


Fig.5.108: Mauritshuis Position

Mauritshuis (Maurice House)
Design Team: Capitola
Hague, Netherland
2019

Museum Type: Art Musuem
Tech. Type: Augmented Reality + Interactive
Tech. Devices: Hololens

Fig.5.109: Mauritshuis Hololens Photo

Introduction

The Mauritshuis is an art museum which collects the best Dutch paintings from the Golden Age including the masterpieces by Rembrandt and Potter. The design team Capitola created a exclusive experience by Hololens for Rembrandt's "Saul & David". In this project, visitors could see some additional content beyond the painting, not only the detailed interpretation and analysis of the artwork, but also the interesting history and mysteries behind the painting. Hololens provided an AR that does not require handheld devices, which also brings visitors a more immersive experience.

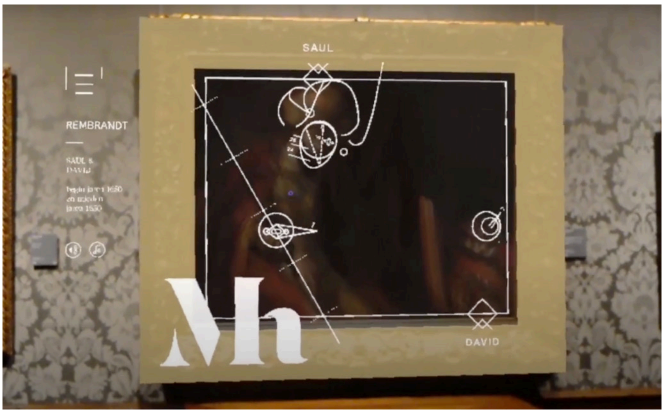


Fig.5.110: Captured from Hololens in the Mauritshuis

Augmented Reality Tour

Morgan Library & Museum
Design Team: MediaCombo and GuidiGO
New York, USA
2019

Museum Type: Site Museum
Tech. Type: Augmented Reality + Interactive
Tech. Devices: Lenovo SmartPhone

Fig.5.111: Morgan Library & Museum Position

Introduction

To create a immersive experience and a narrative storyline, Morgan Library & Museum used augmented reality to reveal stories about two extraordinary people, the Library, and the collections they created. This project is developed by MediaCombo and GuidiGO, they took advantage of the power of AR to blend past and present, combine virtual elements with original space. Visitors can not only see the furniture and decorations of the past buildings, they can even see the changes of portraits on the wall in different periods through the phone screen (Fig.5.114).

Fig.5.112: Visitor using AR tour in Morgan Library & Museum

Fig.5.113: Visitor is viewing the Artwork through Phone

Dambusters Raid with VR

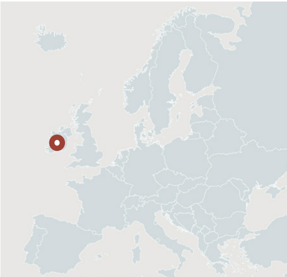


Fig.5.114: Royal Air Force Museum Postion

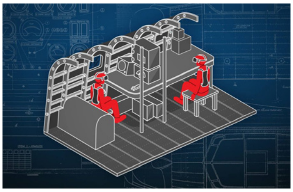


Fig.5.115: Diagram of Users and Space in Royal Air Force Museum

Fig.5.X: Scene in VR

Royal Air Force Museum
Design Team: All Seeing Eye
London, UK
2019

Museum Type: Military Museum
Tech. Type: Virtual Reality
Tech. Devices: HTC Vive

Introduction

In military museums, it is difficult to show the cruelty and shock of war through traditional exhibitst. However, the Royal Air Force Museum and creative technology company have used virtual reality technology to enable visitors to experience being on board a Lancaster bomber during the Dambusters raid of 1943. In order to create a more realistic and immersive air combat experience, the museum has appropriately modified the experience space and built a copy of the cabin interior space. Visitors can experience immersive VR air combat in the built "aircraft".

Fig.5.116: Visitors using VR experience in Royal Air Force Museum

ArtVR

Tretyakov Gallery
Design Team: VRTech Group
Moscow, Russia
2018

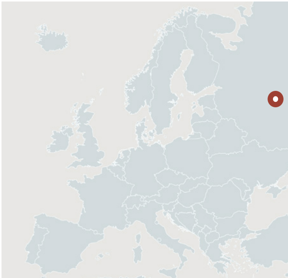


Fig.5.117: Tretyakov Gallery Position

Museum Type: Art Museum
Tech. Type: Virtual Reality
Tech. Devices: VR Helmet

Introduction

The Tretyakov Gallery devleoped a virtual exhibition with VRtech Group, this immersive exhibition aimed to celebrate the legacy of Natalia Goncharova and Kazimir Malevich. In the immersive tour, visitors can have a deep understanding of the their greatest artistic creation, and can enter their studio through virtual reality to witness the creative process behind the work. Not only that, users can also create their own still-life paintings based on interior furnishings. Participants can share their paintings on social media to make the experience more attractive.

Fig.5.118: Tretyakov Gallery Photo

Fig.5.119: Visitor creating painting through VR

Unexpected Growth

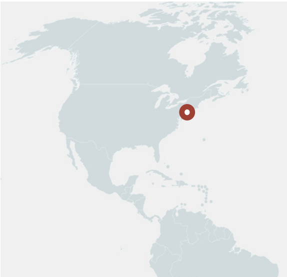


Fig.5.120: The Whitney Museum Postion

Fig.5.121: Visitors using AR experience in the Whitney Museum

Whitney Museum of American Art
Design Team: Tamiko Thiel
New York, USA
2019

Museum Type: Art Museum
Tech. Type: Augmented Reality + Interactive
Tech. Devices: SmartPhone

Introduction

"Unexpected Growth" is an AR installation designed by artist Tamiko Thiel and commissioned by the Whitney Museum. The exhibition uses AR technology to present a terrifying future scene due to the climate. The artist created a colorful underwater world on the top platform of the museum, and these seabed "creatures" are made of plastic waste. The artist hopes to use AR to show the environmental issues caused by modern life. The combination of real space and virtual scene also indicates that future disasters may happen to us at any time.

Fig.5.122: Virtual Scene and Real Space in Phone Screen

Bring Dinosaurs to Life

Museo delle Scienze (MUSE)
Design Team: GuidiGo
Trento, Italy
2018

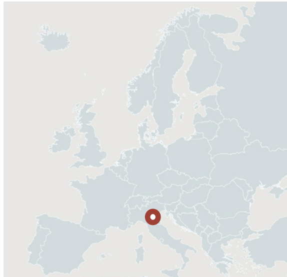


Fig.5.123: Museo delle Scienze Position

Museum Type: Science Museum
Tech. Type: Augmented Reality + Interactive
Tech. Devices: SmartPhone

Fig.5.124: Museo delle Scienze Photo

Introduction

"Bring Dinosaurs to Life" is an AR application developed by GuidiGo in MUSE. The science and technology museum is the best stage to show the age of digital technology, especially for young people, digital products have a unique attraction to them. By scanning the dinosaur fossil skeleton in the museum with this application, visitors can see the restoration of the dinosaur on the screen. Through the immersive experience, a deeper connection is built between the museum and visitors, and this connection is something that cultural institutions must face in the future.

Fig.5.125: Visitors using AR application in Museo delle Scienze

Mont-Saint-Michel HoloLens

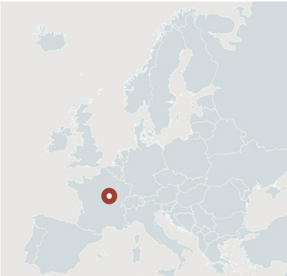


Fig.5.126: Musée des Plans-Reliefs Position

Fig.5.127: Visitors using AR experience in the Whitney Museum

Musée des Plans-Reliefs
Design Team: Microsoft
Paris, France
2018

Museum Type: Military Models Museum
Tech. Type: Augmented Reality + Interactive
Tech. Devices: HoloLens

Introduction

The model of Mont-Saint-Michel, created in the 17th century, is one of its most prized treasures in museum. Starting in 2018, the museum has introduced HoloLens as an AR device to enhance the user experience during the exhibition. This augmented exhibition provides visitors with several different perspectives of the island and show the highlight information through texts, photos and audios. Visitors can compare the physical model in the museum with the virtual model in the glasses. Futhur more, visitors can walk into the virtual model to see more historic architecture.

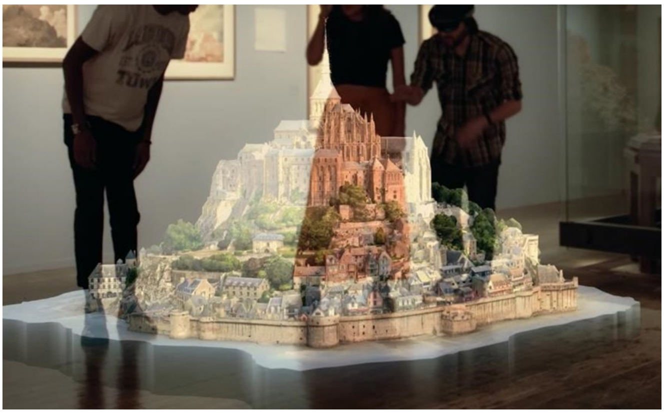


Fig.5.128: Virtual Model and Real Space in Museum

Plaster ReCast

Carnegie Museum of Art
Design Team: Carnegie Mellon University's School of Architecture
Pittsburgh, USA
2017

Museum Type: Art Museum
Tech. Type: Augmented Reality + Interactive
Tech. Devices: SmartPhone

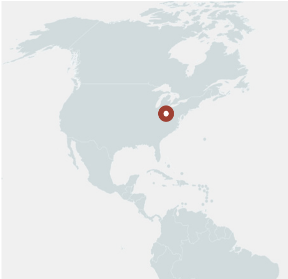


Fig.5.129: Carnegie Museum of Art Position

Fig.5.130: Augmented Model and Real Space in Museum

Introduction

"Plaster ReCast" is an AR application developed by Carnegie Mellon University's School of Architecture and the Carnegie Museum of Art. As one of the projects featured as part of "Copy + Paste: Hall of Architecture", its goal is to test new ways of displaying spatial information. Visitors can use a tablet to enhance the experience of the plaster model of the huge structural wonder. When the user uses the tablet to scan the plaster, the corresponding 3D animation will be displayed on the screen to explain its historical background and information.

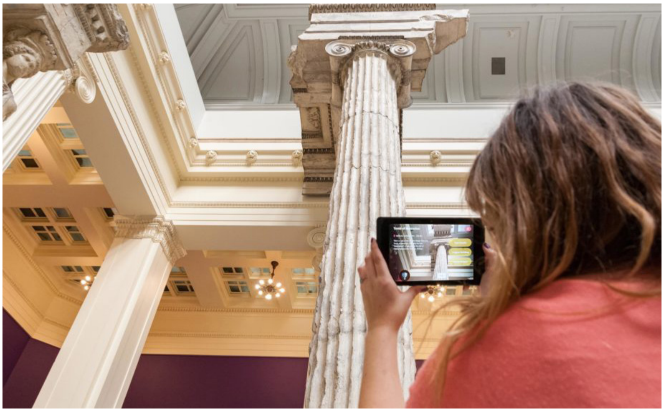


Fig.5.131: Visitors using AR application in Carnegie Museum of Art

Concrete Storm

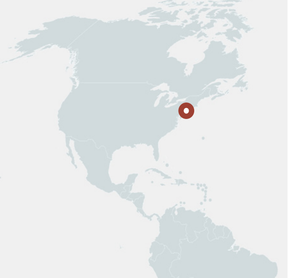


Fig.5.132: The Armory Show Position

The Armory Show
Design Team: Artsy and Studio Drift
New York, USA
2017

Museum Type: Art Museum
Tech. Type: Augmented Reality + Interactive
Tech. Devices: HoloLens

Fig.5.133: Visitors using AR experience in the Armory Show

Introduction

In collaboration with Artsy, the Studio Drift created an augmented art piece named "Concrete Storm" through Microsoft Hololens. It was presented at the Armory show in New York in 2017. When visitors entered the room of the New York Armory Show, all they could see are small columns on the floor. Only when they use Hololens, they would see the exhibition (concrete columns) come to life and strat to explode. In particular, the augmented exhibition freezed when the pillars bursted, and visitors could walk freely in the space to observe the cracked parts floating in the air.

Fig.5.134: Virtual Model and Real Space in Museum

Into the Wild

ArtScience Museum
Design Team: MediaMonks
Singapore
2018

Museum Type: Art and Science museum
Tech. Type: Augmented Reality + Interactive
Tech. Devices: SmartPhone

Fig.5.135: Artscience Museum Position

Introduction

The Singapore ArtScience Museum, collabrated with MediaMonks and Google created an augmented experience with cutting edge technology to walk into the Indonesian rainforest. The project blurred the boundary between reality and virtual. Visitors can experience a virtual environment based on wildlife reserve in Indonesia in a real museum. The virtual jungle adventure is not only about observing animals and plants. The trees that visitors plant in the virtual world, a new real tree will be planted in Rimbang Baling rainforest by WWF.

Fig.5.136: Visitors using AR application in the Artscience Museum

Fig.5.137: Visitors using AR application in Carnegie Museum of Art

Thresholds

Fig.5.138: The National Science and Media Museum Position

Fig.5.139: Virtual Sence in Glasses

National Science and Media Museum
Design Team: Mat Collishaw
Bradford, UK
2018

Museum Type: Science Museum
Tech. Type: Virtual Reality
Tech. Devices: HTC Vive

Introduction

"Thresholds" is an immersive exhibition made by Mat Collishaw. In 1839, the world's first major photography exhibition was opened to the public.180 years later, users use VR glasses to cross time and space and experience an unprecedented photography exhibition. In order to enhance the user's experience in the virtual exhibition, the museum uses white volumes to restore the furnishings in the virtual environment to simulate the user's tactile experience in the real environment. This combined reality and virtual VR experience brings new feelings from additional dimensions.

Fig.5.140: Virtual Experience in Real Space

Changdeok ARiring

Changdeokgung Palace
Design Team: Nexus Studios, SK Telecom, Google
Seoul, South Korea
2020

Museum Type: Site museum
Tech. Type: Augmented Reality + Interactive
Tech. Devices: SmartPhone


Fig.5.141: Changdeokgung Palace Position

Introduction

As a UNESCO World Heritage, Changdeokgung are actively using advanced technologies to help visitors improve their experience during the tour. Nexus Studios collaborated with other organizations to jointly develop AR application "Changdeok ARiring". The application offers a variety of AR experiences such as a virtual dance performance, represented restricted areas which do not open to public. It is worth mentioning that 5G technology has also contributed a lot to this project. With 5G technology, the loading speed of AR has been significantly improved .


Fig.5.142: Visitors using AR application in the Changdeokgung Palace


Fig.5.143: Visitors using AR application in Carnegie Museum of Art

5.4 Conclusion

Case studies as an important research method are positive for analysing the changes and impacts of museum spaces with virtual visual technologies. They helped to understand the impact of AR and VR on the real architectural bodies of museums, and attempts to suggest perspectives for future research in this field. Based on seven detailed case studies and sixteen brief case studies, it can be seen that virtual visual technologies (mainly AR and VR) are already being used extensively in museums with some success. Through the use of virtual technologies and digital media, museums can take advantage of all the possibilities of augmented exhibits to to analyse and respond to visitor requests in a variety of virtual experiences. In terms of the purpose and function of museums, the intervention of augmented exhibits and virtual experiences enables visitors to interact visually with exhibits and completes the entertainment and educational experience of the museum; documentation, objects and exhibits can also be preserved, developed and disseminated through the digital dimension. From the visitor's point of view, the augmented exhibits provide an enjoyable and effective experience, and the virtual experience in the museum space mobilises the participants' enthusiasm. This enthusiasm can be quickly transformed in the internet age into advocacy and inspiration for the experience of real museum spaces.

By examining the context of the case, the designer's inspiration and the strategy and implementation of the design project. It is possible to understand more effectively the position of the different actors in the application of new technologies in museums. The type of museum, the shape of the space and the type of technology all have a different impact on the final result and experience of the visitor. In addition, the different actors (museum, designer, visitor), the real space of the museum and the augmented exhibits interact with each other in a variety of ways and create new logical relationships during the virtual experience. These interactions and relationships form a new kind of network based on digital elements. Within this network, the scope and context of the architectural space is upgraded and in this case the physical space of the museum is transformed into an augmented space. In the concluding section of Chapter 2, the role of augmented exhibits in museum spaces is broadly grouped into three categories: presenting additional information, building unbuildable spaces and creating new experiences. These characteristics are also well reflected in the experiences and user feedback from the case studies described above. These three characteristics are represented in different ways depending on the types of museum and the virtual technologies used in the case studies.

At the additional information level, there will be questions as to whether too much digital information will deprive viewers of their senses and disinterest them. Firstly, the role of museums themselves is becoming visitor-based[1], which means that they are not just a "shrine" for elitists, but also for a more culturally diverse audience. Detailed, easy-to-read explanations and information can help people to understand the content and cultural context of museum exhibits more accurately. The information presented through virtual visuals goes beyond the mere visualisation of textual descriptions and can be used to guide the visitor through the exhibits in an interactive manner

1. Weil, Stephen E. "Transformed from a cemetery of bric-a-brac." *Perspectives on outcome based evaluation for libraries and museums* (2000): 4-15.

(as the case *"ArtLens"*). Secondly, the additional information is not only an extended interpretation of the textual descriptions in the museum space, but can also be recreated from the original exhibits in a different dimension. This additional information can be understood as a new virtual art on top of the original artwork (as the case *"ReBlink"*, and *"Mauritshuis HoloLens"*), the augmented information that cannot be replaced by traditional mediums (text, images, etc.). This is not only because the virtual information is three-dimensional and interacts with the real world, but also because it is based on the original exhibit, and it is in contrast to the original (real) information that this additional digital information can be used to maximise the value of the experience.

Virtual technology provides a suitable opportunity and platform to help museums create unbuildable spaces at the unbuildable space level, as has been demonstrated in many of the cases mentioned above. In the case of *"SmartGuide in Casa Batlló"*, AR technology was used to restore and recreate scenes from decades ago, and in this way, the aim was to create an unbuildable space. In the case of *"Rhomaleosaurus: Back to Life in Virtual Reality"*, the entire exhibition hall is designed as an underwater world, breaking through the physical limitations of the building and also achieving the same goal of creating an impossible space. Further, this mode of creation will lead to new forms of art based on the combination of digital elements and real space (e.g. the case of *"Invasive Species"*). AR and VR can enrich the means by which artists and designers create space and can inspire their creators. This pursuit of sensory stimulation seems to contradict museum exhibitions' purpose and transforms museums into entertainment-centred playgrounds. In fact, museums' core functions, namely collection, conservation and exhibition, remain unshaken in the digital age. Entertainment and digital content can be seen as an extension of physical museums or as "digital reflections" of physical museums[1].

Falk and *Dierking* proposed an interactive experience model. They mentioned that visitors' experience is not necessarily passive, and it is closely related to the personal and social environment[2]. *O'Dell* also agreed this pointview from cultural sociology, and indicated that in postmodern society, visitors are no longer observers or interpreters; instead, they are active experientialists and even meaningful creators and actors[3]. This paradigm shift and upgrade in the experience paradigm is more prominent in modern society, especially in the Internet era and the popularity of virtual vision technology. Based on AR and VR, the visitor's attitude and experience in the real museum space is changing from passive to active. The introduction of interactive modes makes the entire exhibition process active and full of variation. In some cases, it is clear to conclude that with the intervention of a virtual experience and active interaction, users will more efficiently access the information that the museum is expected to present. In the case of *"Hacking the Heist"*, for example, a more active approach to guidance and display design allowed visitors to gain a deeper impression and understanding of the lost painting. The over-interaction seems to lead the museum space back into the entertaining situation mentioned above. The solution is to dissipate the overdrawn entertainment properties of museums through the professionalisation of virtual information based on cases' relationship networks. Virtual information should be constructed through good cooperation between cultural heritage experts (museum curators, historians, archaeologists, etc.)

1. Styliani, Sylaiou, et al. "Virtual museums, a survey and some issues for consideration." Journal of cultural Heritage 10.4 (2009): 520-528.

2. Falk, John Howard, and Lynn Diane Dierking. The museum experience. Howells House, 1992.

3. O'dell, Tom. "Tourist experiences and academic junctures." Scandinavian Journal of Hospitality and Tourism 7.1 (2007): 34-45.

and information science experts to ensure the core functions of the museum. The display value of exhibits and the authenticity of place and experience that museum spaces provide remain essential supports for museums in the digital age.

CHAPTER 6

PILOT PROJECTS

6.1 Introduction

In this part of the discussion, the author will elaborate on the application of AR and VR in the exhibition space for the specific two projects involved in the exhibition.

For the AR project I select the "Seeds on Mars" project cooperation with Stefano Boeri Architetti. The project presents the future architectural form in the form of AR, and was announced in the Shanghai SUSAS exhibition in 2017, and won the public's praise. The VR project is not aimed at a specific museum, but the author tries to reconstruct the VR by the famous work of the artist Escher. Through this virtual rebuild, the author's reinterpretation of the artwork proposes a virtual construction and an immersive experience. Based on the research of this virtual project, the author provides a new possibility in the appreciation of art works.

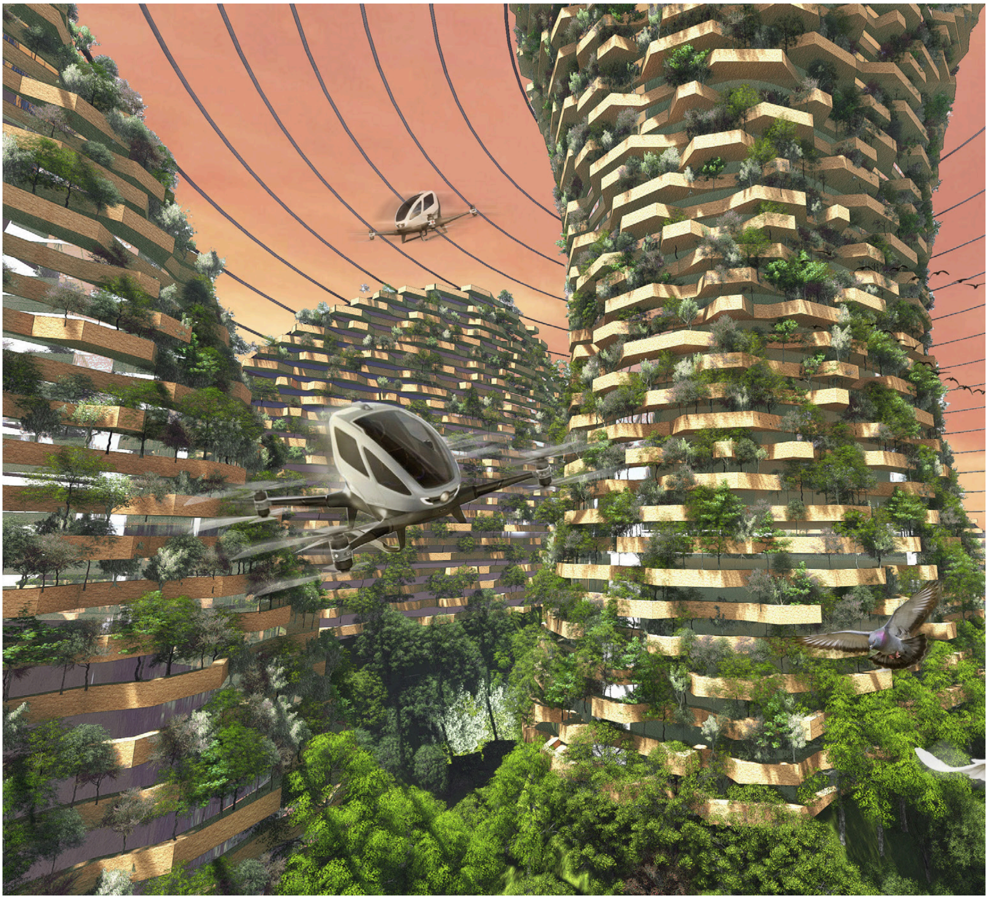


Fig.6.1. Concept Rendering image of
Seeds on Mars

AR Pilot Project: Seeds on Mars

SUSAS

Design Team: Stefano Boeri Architetti
Shanghai, China
2017

Fig.6.2. Site of Exhibition, Silo of 80,000 tons

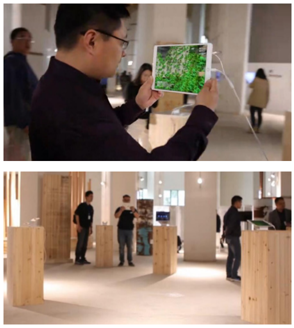


Fig.6.3. Visitors using AR in SUSAS exhibition

Museum Type: Art Exhibition
Tech. Type: Augmented Reality + Interactive
Tech. Devices: SmartPhone and Tablet
Tech. Support: ARchi Susas

Introduction

Inside the theme of SUSAS 2017 "this connection – sharing a future of public space", Stefano Boeri Architetti and Tongji University's Future City Lab will take visitors to Shanghai 2117, in a future interstellar city view.

Despite being the second-smallest planet in the solar system Mars has always attracted interest since ancient times, benefitting by its peculiar red colour that makes it visible also to the naked eyes. Chinese ancient astronomers dubbed it "the fire star". In the 20th century, the spaceflights and the early scientific speculations that its surface conditions might be capable of supporting life, has inspired a great interest on the Red Planet, and many fictional representations have been proposed, The possibility that Mars could be colonized by humans has been investigated, desired and treated by many fields.

2117, the human being is at a critical moment. The pollution, the environmental crisis, the unlimited urbanization and urban sprawl have changed our planet from green to grey. In a century humanity was not capable to reverse the warming of the planet and people cannot escape the obvious results of sea level. The great metropolis of Shanghai is now flooded by water. In this view, a visionary project in collaboration with the spatial agency has been proposed and Shanghai has been chosen as the pioneer city: "Vertical Forest-2117 Seeds on Mars" will set a colony of Shanghai on the red planet.

Concept:
The author was involved in the discussions as part of the design team from the very beginning of the concept phase. At the initial stage of the project, it was determined that we wanted to build a future-based design concept of a hypothetical future home on Mars. This scenario also needed to be combined with a vertical forest form of architecture that was both species-diverse and green. This is a future-oriented design with a biased concept, and we have tried a

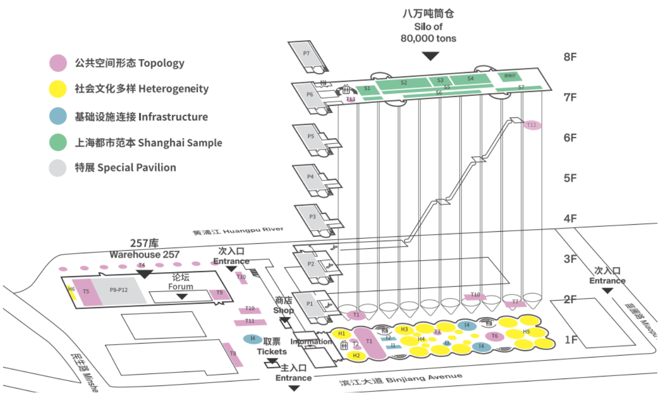


Fig.6.4. Exhibition Map

variety of solutions, such as traditional exhibitions, architectural models and videos. But this does not seem to give the audience a shocking effect. And building a small size experience space seems too expensive for this future project. So we want to bring this project to the visitors in a more realistic and immersive way. In view of the complex equipment required by VR and the need for administrator maintenance, we have taken the project on Mars 100 years later to bring visitors through AR. With the iPad, put the user in the Mars Seeds and experience the vertical forest on Mars from the first perspective through the screen.

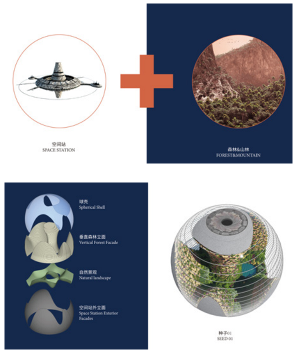


Fig.6.5: Concept Diagram

The concept of the project is to design a giant sphere model as the foundation of the space station. The

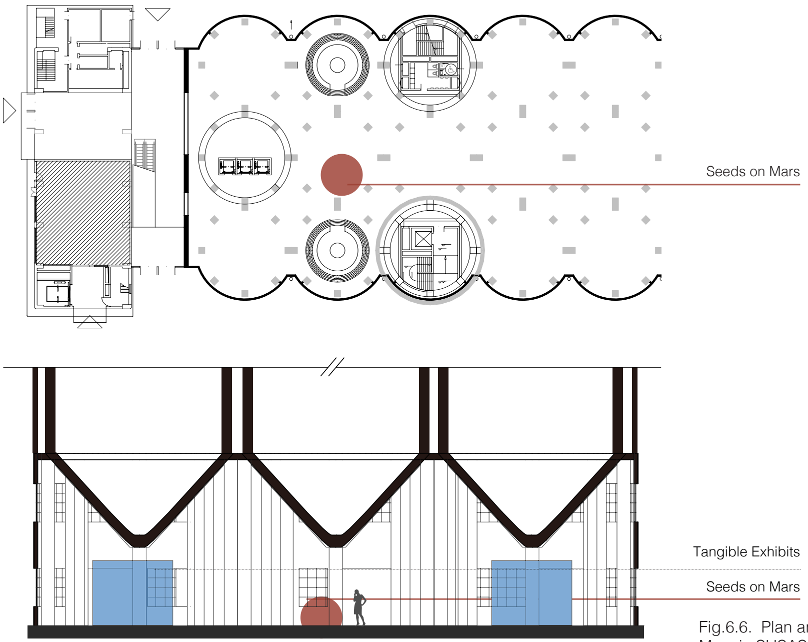


Fig.6.6. Plan and Section of Seeds on Mars in SUSAS
Source: Made by Author

interior of the sphere is the natural landscape plus the residence of the vertical forest. The whole sphere is placed on the future Mars as a "seed" (as shown in Fig.6.5). This in itself is a project of future exploration significance, so obviously it can't be built truly. It is the best choice to show the environment inside the sphere through AR. In this way, visitors can not only see the "seed" pictures from a macro perspective through videos and rendered pictures, it also provides an immersive experience that allows visitors to "live" into the vertical forest on Mars.

Process:

To achieve this goal, we first made an exquisite model of the holding sphere in Rhino. During the production process, the model will be layered according to the

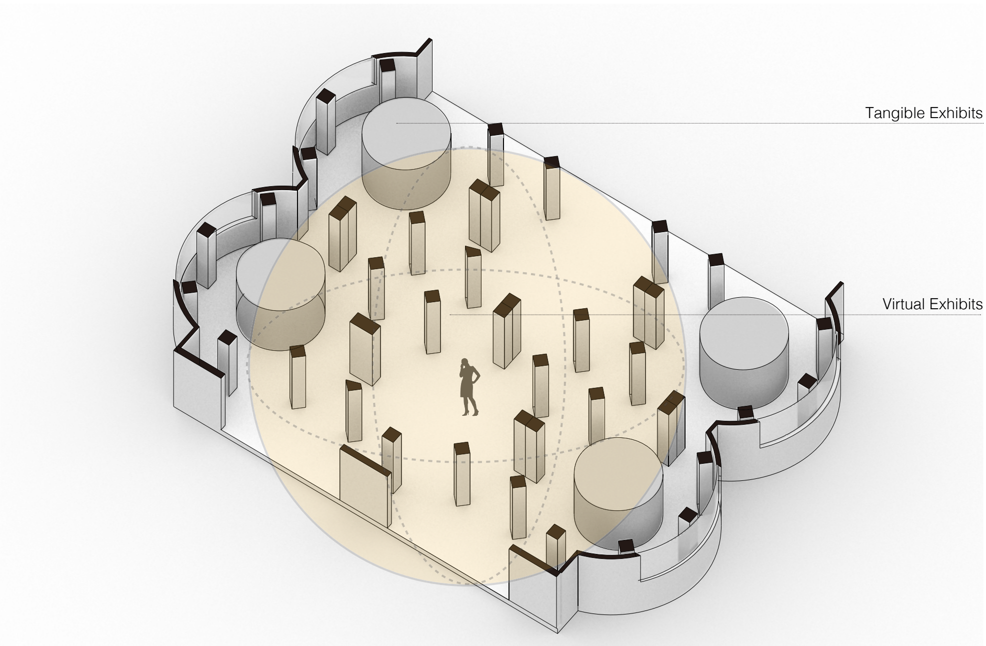


Fig.6.7. Axonometric Diagram
Source: Made by Author

material, which is convenient for pre-rendering work when it is transformed into an AR model. When making the model, we encountered a difficulty: due to the large amount of vegetation material in the solution, these vegetation will occupy a large amount of system memory, which leads to the process of converting into an AR model. In order to solve this problem, we optimized the vegetation model and used random deformation (rotation angle and zoom ratio) to reduce the duplication of the model being copied. After the model is completed, we need to export the Rhino model in the form of fbx to Unity software to edit the AR program. With the help of ARchi Susas, we quickly got the preliminary shape of the AR model. The basic material settings have been completed in the original model. On this basis, we need to complete two additional steps. One is to determine the initial position of the visitor in the AR experience. We chose a square in the middle of it as the initial location of the AR experience. This location has a wide field of vision and is in line with the height of human sight (1.6m). Another thing that needs to be adjusted is the lighting system. Since this program is a program on Mars, we did not use the traditional solar lighting and sky system, but used a black background as the vast universe.

Fig.6.8. VR experience in Glass
Source: Made by Author

VR Pilot Project:
Impossible Space through VR

Introduction

This project is focusing on the immersive experience in relation to architectural spaces, proposes a research on "Impossible Spaces" through virtual reality, aiming at exploring spatial navigable configurations that are visually sensible and perceptible however impossible to construct in the physical world. Virtual Reality will be used as a digital representational tool useful not only to show architectural materiality, but also to study the mathematical and geometric logic compositional principles, as well as to appreciate aesthetic issues of the work. Maurits Cornelis Escher, a versatile graphic artist, has created many impressive works of graphic art throughout his life, including some representations of "Impossible Spaces". These graphic art works, are often strongly based on mathematical relationships among shapes, figures and space. Additionally, interlocking figures based on the use of black and white to enhance different dimensions are explored. With the help of VR technology and equipment, these potentially multi-dimensional graphic works of art can be digitally reconstructed and expressed in the form of three-dimensional spatial simulations. The relationship between space, geometry and art would be then studied by simulating the digital experience of three-dimensional environments. In this paper, we will focus on the graphic work Relativity to which we refer as to an impossible space.

Concept:

In order to achieve this type of visual simulation, it is necessary to prepare the three-dimensional whole model of the space in advance, supplemented by certain rendering techniques to enhance its realism. In this research, we have chosen to use static VR, that is, a purely visual type of VR, where the user is not free to move within the given space. We selected some relevant viewing points in this model and rendered 360-degree panoramic images based on those camera points. Once we got the mentioned images, we could import them into a VR equipment (VR glasses through phone in this case). With VR equipment, users can then enter and experience the 3D dynamic visual perception of the space we simulated at any time. As already said, we have chosen to reconstruct the spatial configuration of the Escher's art work "Relativity"(Fig.6.9). In spite of its apparently hypnotic feature, and apart from the absence of a unitary – or, if we prefer, of the multiple action of the- gravity force, Relativity is a perfect regular space in the Euclidean world, therefore it seemed to work well for a simple 'entry level' test case to experience. The three directions characterizing the real space are here respected, so that the construction of the 3D model has been easily carried out, also with the help of the light, generated by a light source located above the upper limit of the image. The clear graphic feature, despite the small size of the original lithography (27,7 x 29,2 cm), has been of great help to understand the architectural space and its organization, as well as

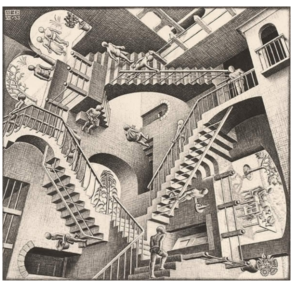
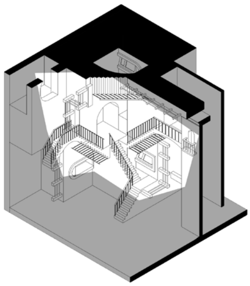


Fig.6.9: M.C. Escher, Relativity, Lithography, 1953 MoMA, New York, USA

in the geometric reconstruction of its digital version, also thanks to the further help offered by the human figures populating various key areas of this fascinating oniric place. The overall structure can be considered as a composition of various 'pieces' of very similar architectural spaces, mainly connected by staircases, and differently oriented one another, walkable as a space station in the cosmic space.

Progress:
From a geometrical point of view, based on the analysis of the lithography itself, the work is connected by stairs located in different planes. For example, as shown in Fig.6.10, surface A works both as the side wall for staircase No.1 and as the lower ground for staircase No.2. Following this space and its geometric logic, we first created a 3D model in which only the 3 main sides were shown, as represented in Figure 6. As a first stage, we strictly focused on the portion of space visualized under the cone of view proposed by Escher (Fig.6.11a). Then, as a further check, we also tried to hypothesize a possible way to complete the construction of the space including the parts not appearing in the Escher's representation (Fig.6.11b), which confirmed the possibility to realize this architectural interior as a real object in our real space. In order to further complete the immersive experience process, we selected some of the characters in the


(a)

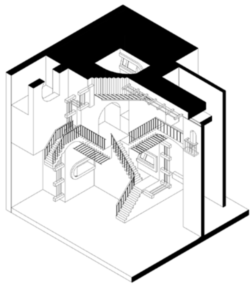

(b)

Fig.6.11: Axonometric views of 3D digital reconstruction of the space represented in Relativity: (a) the space actually visible in the Escher's work; (b) hypothesis for a full reconstruction
Source: Made by Author

Fig.6.10: Early analysis of Relativity: main orientations (detail)

painting, as shown in Fig.6.12 (left), and established these characters' viewpoints in the model, as shown in Fig.6.12 (right). Since we have selected five people in the original painting based on the corresponding different coordinate systems, we used VR technology to simulate the space observed by these five people at different water planes. Consequently, the whole spatial system rotates according to the change in the coordinates of each point of view.

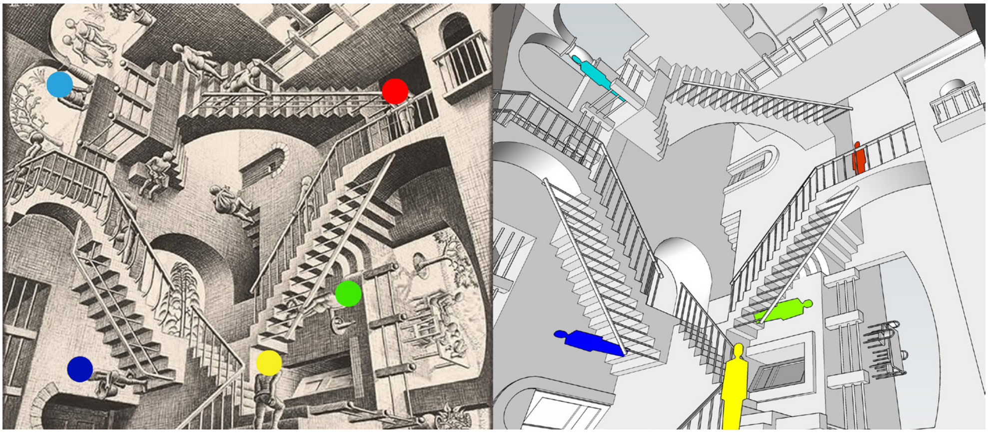


Fig.6.12: The selected viewpoints in the original work and in the digital reconstruction
Source: Made by Author

Through the perspective supposed to be seen by the selected different people appearing in the painting, and the related images graphically reproduced according to their position, we can further understand the Escher's shaping of this impossible space through a unique panorama view. Instead, the continuous change of the viewing point and its orientation, seems to be the only possible way to experience this space from inside, that is, without any privileged, primary, or absolute sight position. Therefore, a kind of perceptual 'relativism' emerges, since none of the visions proposed is more 'true' than the other. Neither our vision, that is, the one proposed by Escher, since it shows, again, only one among the infinite number of images available in that multi-gravity environment. In the Fig.6.13 we have collected the five images generated by VR according to the five points of view selected.

Based on the above results, we have designed a set of small programs for visualization, that can support the experience of a simple visual interaction. In this design, one can quickly switch between different perspectives by clicking on the color ball in the interactive image. From each point of view is then possible to move the camera and look around the interior space.

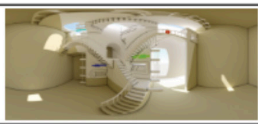
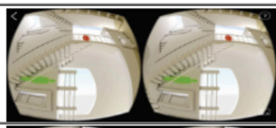
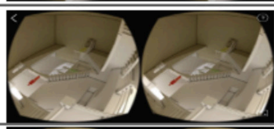
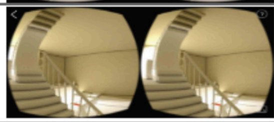
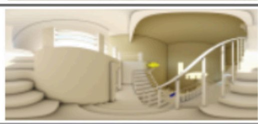
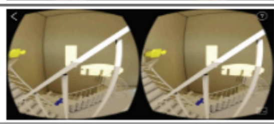
Point	VR Spherical Image	VR Experience in Helmet
Point1		
Point2		
Point3		
Point4		
Point5		

Fig.6.13: Series of VR Spherical Images
Source: Made by Author

CHAPTER 7

FROM FUTURE MUSEUM TO FUTURE CITY

7.1 The Changing Role of Museums

As an important cultural institution, museums play an irreplaceable role in the inheritance and dissemination of historical culture and art. However, the continuous development of social life and science and technology has brought about continuous changes in people's cultural consumption needs. The management method and spatial form of the museum also need to be adjusted continuously with the changes of the times, to adapt to the new conditions of the people and society, and to better assume social and cultural responsibilities. The museum itself recognizes the potential challenges brought about by these changes. The museum is reshaping itself to adapt to the new era and keep up with the rhythm of the digital world. There seems to be a natural gap between historical and cultural and artistic heritage and the lives of modern people. How to construct a sustainable and participatory strategy to connect modern urban life filled by digital virtual information and "old" exhibits are what museums need to explore. The rise of the Internet and the prevalence of shared culture have caused museums and other cultural institutions to gradually lose their appeal to young people. This makes the museum an island where cultural elites gather. Therefore, the increasing challenge that museums are now facing is how to establish contact with young people outside the cultural elite. In other words, museums must actively face the impact of this era and try to reverse the lack of attractiveness through digital technology and new exhibition models. In the process of museum transformation and development, the key to reversing this situation is to attract the attention of visitors. The role of the museum itself is also changing.

The museum is the best starting point to explore the cultural heritage of a city. In the era of consumption upgrading and the digital revolution, the role of culture in urban development is becoming more and more prominent, and the public cultural space of the city is also expanding. The museum, as a centre of urban cultural activities, also a treasure trove of resources that carries urban civilization, has gradually become a high-quality and precise city branding. The museum is no longer limited to the display platform of urban culture, but also an essential component of urban brand building, and has become one of the most active parts of urban development. From the perspective of space, the museum has developed from a single collection and education place to a multiple formats space that integrates comprehensive functions such as cultural and creative research and development, ecological leisure, entertainment and so on. From the perspective of content, the museum has entered a new narrative method, and it has higher requirements for exhibition logic, theme mining, and service support. Future more, Emerging technologies such as AR, VR, artificial intelligence, etc. will change the museum's exhibition form. The intervention of virtual vision technology dramatically expands the existing form of traditional museum exhibits with contemporary aesthetics and presents visitors with an open and integrated space design, and an innovative and interesting interactive experience.

Museums are the best place to experiment with new technologies and forms. For future museums, it should not only solve the problem of "what to see", but should pay more attention to the problem of "how to see". "What to see" studies the social and cultural expectations, which is a guide to the culture and aesthetics of the new era. And "how to see" requires the creation of new interactive modes with the support of new technologies and even the redefinition of exhibition space. As a pioneer of culture, museums should try to create a starting point for a new cultural experience, allowing viewers to get a unique experience through participation and interaction. And then upgrade the museum to a place for culture and interaction and experimental space to increase creativity.

Unlike traditional historical and cultural cities such as Rome and Paris, Small cities and emerging cities urgently need to enhance the cultural heritage and urban image of the entire city through iconic architecture. Bilbao Guggenheim Museum (Fig.7.1) is It is a very classic case, the city has been rejuvenated by the modern museum*(The museum was opened as part of a revitalization effort for the city of Bilbao. Almost immediately after its opening, the Guggenheim Bilbao*

Fig.7.1: Bilbao Guggenheim Museum Photo

became a popular tourist attraction, drawing visitors from around the globe. In its first three years, almost 4 million tourists visited the museum, helping to generate about €500 million in economic activity. The regional council estimated that the money visitors spent on hotels, restaurants, shops and transport allowed it to collect €100 million in taxes, which more than paid for the building cost.). It is foreseeable that the role and value of the museum are constantly innovating and deepening with the management innovation of the city. As an important part of urban brand marketing in the new digital era, the future museums need to adopt a more open attitude, absorb and integrate different elements of the city, and give full play to their special values. A museum in a city should not only be regarded as a place to display collections, but an architectural space with the city's brand identity. The role of the museum has also changed from a collector of cultural heritage in the city to an urban activator with creative value and experience value. One of the declarations of many newly built museums is to become the city's business card and tourist landmark. This should not just stop at the appearance of the building, that is, to show the representation authenticity. The intervention of new media art allows the authenticity of experience to bring new value to the architectural space. The value of creativity interacts with the value of place. With its strong sense of presence, flexibility and interaction, it has become an indispensable part of future museums.

Whether it is now or in the future, the "display" function will always be the unshakable core function of the museum. With the rapid development of technology and art, museum display is no longer a simple static mode. The architectural space, curatorial concept, and experience of digital exhibits have entered a new era that is more and more open and diverse. To be sure, museums will play more different roles in society in the future, and the functions carried by museum buildings will also be more diverse.

First of all, the public education and research functions of a well-developed museum in the future will not be as simple as it is now. Digital cultural environment, advanced visual technology and new media will greatly enrich educational methods. The perfect information and convenient way of dissemination make museum education have sufficient resources. The customized augmented space can make education more targeted. For user groups with different attributes, they may receive different information when facing the same exhibits in the museum. Even the same visitor, at different times, at different stages, will have different viewing experiences when visiting the museum. In terms of academic research, the extensive use of new technologies has played a significant role in the protection, research, and communication of works of culture. Relevant cultural relic reproduction, three-dimensional 3D image modeling, historical deduction, etc. have revived many historical and cultural heritages, and the exchange of different knowledge will become more frequent. In the future, the use of related science and technology methods in museums will be more advanced and mature, which means that the research field will also expand unprecedented.

Entertainment content is also one of the many things visitors can expect from the museum space in the future. As new media and new technologies have changed exhibits and exhibition spaces, visitors can develop a new interactive relationship with exhibits and spaces. Augmented exhibits and space mean that only in the museum space can you fully experience the best combination of digitization and exhibits. Compared with education, people want to get more entertainment experience. The general audience does not necessarily come to the museum for learning or research, nor for acquiring knowledge or skills. The entertainment and interactivity can effectively enhance the attractiveness of the museum. Through the enhancement of technology and art, the museum space itself has the degree of communication in the Internet age. Once an entertaining exhibition is launched, it will cause a social network boom and form a thematic phenomenon. I have to admit that the role of museums needs to evolve with the progress of the times and changes in people's needs. In a culture that advocates convenience and sharing, museums need to narrow the distance with visitors. The Internet, the best tool in the era of new media communication, has given museums a platform for transformation; but at the same time as the transformation, museums may lose some of their due characteristics: with the dignity and quietness, people are In the museum, admire the classics of centuries, hang around in front of the intuitive artwork, and contemplate in the exhibition hall. Now, this relationship will be reshaped, and the experience space based on interaction and communication will be reborn in the museum of the future.

Generally speaking, new media and virtual visual technology have had a huge impact on museums and art institutions. This is related to people's understanding of curatorial exhibitions, art practice, and museum technology construction in the future. Contemporary culture is embedded in the society shaped by digital and other new technologies. This culture increasingly involves participation, collaboration, social connectivity, and interaction. Digital culture and digital practice have redefined the roles of space designers, audiences and curators, and their development has brought new challenges to traditional architecture and exhibition spaces. The museum of the future will become a experimental place for new media and new technologies. As a starting point for experiencing urban culture, the future museum will become the activator of the city. At the same time, the museum will also undertake more education, research and entertainment functions in the future.

7.2 A Contemporary Approach for Future Museum Design Through Virtual Technologies

As mentioned in the previous article, virtual vision technology has already had a certain impact on museums. With the maturity of this technology, this impact will become more and more intense. The popularity of virtual vision technology will be accompanied by the improvement of the processing performance of the device, the network revolution brought by 5G, and the blowout development of artificial intelligence have an inestimable impact. This has forced a change in the museum space that is mainly visually oriented, and as architects and designers, in the face of future museum design, new contemporary design approach will emerge.

1. User-centered design (UCD) and experience-driven framework:
The User-Centered Design (UCD) concept was put forward 50 years ago, and it involves a variety of disciplines including product design, environmental design, and architectural design. According to different design objects and fields, there are also differences in specific manifestations and execution methods, but

their essence is the same. The UCD concept is of great significance. It is not only closely related to our vital interests, but also related to the development of society and the sustainability of the ecological environment. In the development environment of new technology and new media, the connotation and design methods of UCD are constantly evolving and changing. Grasping the development context of the UCD concept under the new situation, and comprehensively understanding and reflecting on the UCD concept will help designers have a deeper understanding and grasp of the relationship between design and people, society, and the environment for better design practice.

Experience design can actually be understood as the user experience design mentioned above. Under normal circumstances, experience design is an interdisciplinary design and service. Any design-related or user-related discipline can involve experience design, regardless of whether the discipline is traditional or digital. At the present time, the main application direction of user experience design is digital media, but its core element, that is, the user-centered design concept, has broad application prospects in various disciplines, especially the disciplines dominated by design types.

UCD is essentially the same as experience-driven design, that is, taking user needs as the first criterion. It is a general trend to apply this design method to the field of museum design in the future. The future museum is a comprehensive public building with multiple functions such as collection, display, education, entertainment, and social activities. Its design must be innovative, modern and user-centered. Only in this way can the modern society's pursuit and expectation of the museum as a city brand be satisfied. When more consideration is given to the needs and behavior of visitors in the exhibition space and their interaction with the exhibits, the museum space will become more attractive and thematic. Unlike traditional architectural space design methods, user experience emphasizes the iterative design process, and designers need to update to meet the different needs of users at different stages. In the museum design, the space of the building, the service and experience of the museum should be considered more comprehensively. Thanks to the shared cultural system in the Internet era, the needs and feedback of users, namely visitors in museums, can be more easily and accurately obtained. And how architects face and respond to these quick and positive feedbacks are the challenges that need to be faced in future display design. Digital products are updated frequently in modern society, which shows that users' feedback and needs for products are constantly updated and

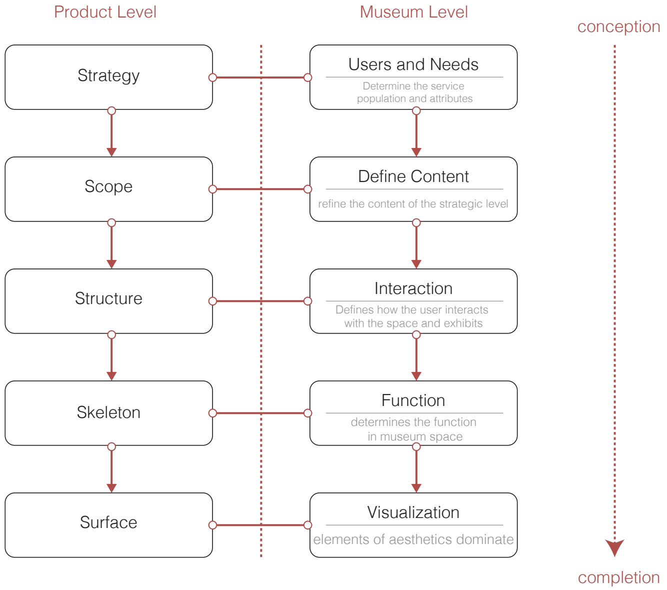


Fig.7.2: Diagram: Experience-driven design approach in museum desugn
Source: Made by Author

changed. Although the architectural space cannot be renovated and rebuilt so frequently, it can accelerate the iteration speed of the space experience based on the enhanced space and interactive space as well as customized services.

2. Virtual vision technology intervenes in design phase: Virtual vision technology is not only a platform for architectural visualization, but also an aid for designers in the design stage. Virtual vision can superimpose the unfinished architectural form and spatial organization in the original space through augmented reality. Compared to rendering, this kind of visualization has an unparalleled advantage. The design team can pay more attention to the content of the design itself, so as to complete the overall construction project more effectively.

Both AR and VR technologies have begun to explore in related fields and have achieved some results. For example, the IKEA APP can already put virtual furniture into the indoor environment through AR. Users can observe the appearance of the furniture at home through the mobile phone screen (as shown in Fig.7.3), and adjust the different colors and materials of the furniture through the program. It is the goal pursued by

Fig.7.3: User using IKEA Application
Source: https://mobile-ar.reality.news/news/apple-ar-houzz-arkit-app-beats-ikea-app-store-0180132/

AR applications to be able to preview its actual state at home before the formal purchase. This experience has changed many processes regarding interior and architectural design. Extending this concept to the entire design process, it is foreseeable that this will change the workflow of architects. Architects and designers often accompany drawings. These two-dimensional images and graphics are difficult to fully reflect the appearance of architectural elements when they are built, although it is an unique skill for the architects to transform these drawings into their mind with appearance when they are built. Directly previewing the state of buildings and spaces when they are not built and making dynamic modifications and coordination may be an important process for future standardization.

VR is another situation. In a completely virtual immersive experience, users can freely explore in the virtual space that has been designed. As a visualization tool, VR can not only provide immersive rendering results of buildings (Fig.7.4), but also a collector of opinions and evidence. The VR immersive experience not only allows users to foresee the visual expression of buildings visually, but also collects user behaviors during the experience. Specifically

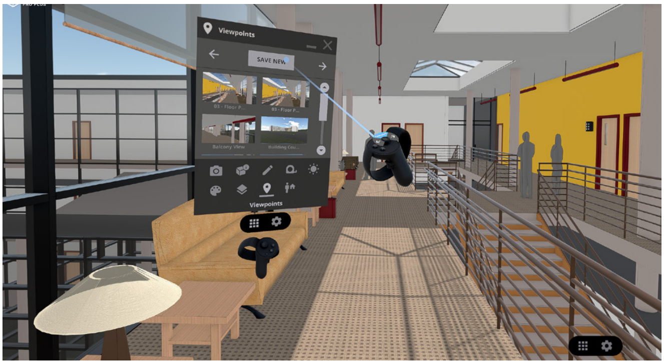


Fig.7.4: VR program assisted architectural design
Source: https://blog.irisvr.com/architectural-vr-walkthrough

in museums, eye-tracking technology can be used to discover which part of the architectural space or art exhibits is more attractive. These data can help designers better carry out their work and be used to prove some architectural and spatial theories. With the help of real-time rendering technology, designers can also create directly in VR, which also expands the dimension and experience of the traditional "canvas".

3. New spatial model based on virtual vision

In the digital age, new technologies and new media will give birth to an architectural form that is more suitable for experiencing virtual space and enhancing space. New materials, new interaction logic, ever-changing human scale and the way people interact with space will redefine the changes in spatial form under new technologies. The new space that brings new experience through virtual vision technology will redefine the museum space in the future. We are currently unable to determine what the specific form of this future museum space is, but it must be different from the current spatial form.

First of all, it is interactive, and interaction is a trend in future architecture. As Carlo Ratti said*:"Ultimately, technology recedes into the background, and interaction is brought to the fore."* New technologies have greatly enriched the interaction mode between visitors and exhibits in the space. The change of interaction distance affects the distance relationship between exhibits and visitors, and the space should respond to this change. This kind of interaction is not only limited to exhibits and visitors, but also exists between visitors and space. This interactive space experience will make visitors have more desire to explore, and also promote the mobility and activity of visitors in the space. Secondly, the future exhibition space should focus on the mobilization of multiple senses. Virtual technology is currently mostly based on visual technology. At the visual level, new media and new technologies have upgraded the display mode and space mode. The multi-sensory mobilization of touch and smell can better help visitors enter the immersive space. For example, in the National Science and Media Museum (Fig.7.5), many white boxes are placed in the exhibition space. These boxes are almost meaningless without the experience of VR technology. In the VR environment, these white boxes become virtual glass display stands; and visitors can "touch" them. This is the result of multi-sensory invocation. In the future, trying to enhance the experience through the use of spatial context will also be something that the museum needs to consider and put into practice during the design process.

Fig.7.5: White boxes in museum space(left) and its virtual sense in VR glasses (right)

7.3 Redifining the Design Framework

7.3.1 Redifining the Relationship Between Exhibits and Users

Under the influence of virtual vision, the direct relationship between the exhibition and visitors continues to expand. In traditional exhibitions, the relationship between exhibits and visitors is passive. The exhibits are viewed by visitors, but visitors cannot touch or have more in-depth communication and interaction with the exhibits. In the future, the relationship between visitors, space and exhibits will be as shown below.

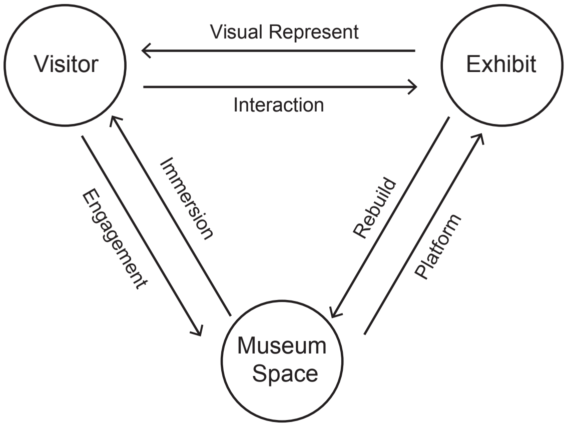


Fig.7.6: the relationship between visitor, exhibit and museum space
Source: Made by author

Visitors interact with the exhibits through various behaviors and means (digital or physical) in the exhibition space. A suitable interaction mode will reduce the sense of distance between the visitor and the exhibits. At the same time, the exhibits will be fed back to them in the form of visual expression. The museum space provides a platform for exhibits. Space presents the exhibits through effective organization. The museum space here has the functions as a container or a platform. The exhibits also gave the building a new form of space. Due to the presence of the exhibits, the attributes of the space have also changed. That means exhibits have rebuilt the museum space. The relationship between the space and the visitor is easier to understand: the visitor participates in the museum space, and what space can bring to the user is to bring the immersive experience to the visitor through design. In the future, exhibits can also provide visitors with customized services based on big data and artificial intelligence to display the content of exhibits required by customers. For example, the same exhibit displayed to users of different ages will give different explanations and even provide different ways of interaction. This also means that architects and designers need to make multiple designs for different user groups.

7.3.2 Redifining the Roles of Architects

As mentioned earlier, architects will take on more and longer-term responsibilities in the future museum design. The transformation of the role of the architect, the architectural design process may be a dynamic, long-term, and will be adjusted in real time based on user feedback. Nowadays, the updating of buildings is very slow. Some construction projects often take years to maintain and update. In the future, some spaces based on virtual technology can be updated as quickly as computer software. This update may be like updating the software now, a new version will be provided in a few months.

This update will give the users the opportunity to be involved in part of the design process as well.In the Internet age, the opinions of visitors will be easier to be discovered and directly fed back to the designer in digital form, and intelligent and digital access methods also make these data better collected. Where visitors stay for more time in the process of viewing the exhibition; what their eyeballs will be attracted to; and when they feel tired; these can all be captured by digital equipment in future museum design. These data also provide sufficient data support for architects to revise their plans. The customized space further enhances the role of the architect. The exhibition space in the traditional sense is aimed at all visitors, which actually cannot meet all their needs. When children, young people and cultural elites face the same piece of art, what they feel or what they want to learn from a museum should not be the same. The customized enhancement space can be based on the different attributes of the user, and the targeted design of the virtual experience exclusive to the user group. Even the same group of visitors will have different feelings and gains at different times and places (Fig.7.7)

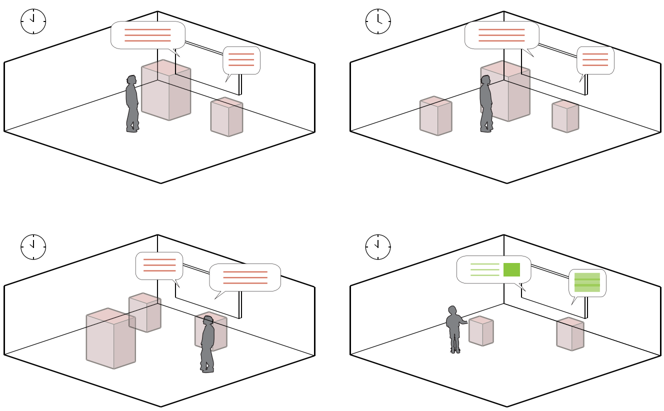


Fig.7.7: Customized spatial diagram: virtual content will change depend on different time, different place and different users
Source: Made by author

Virtual and augmented spaces will not make architects unemployed; on the contrary, they provide architects with more opportunities and possibilities. Virtual and augmented spaces may look like online game character skins (the appearance of game characters, some designs require users to pay for them, usually these designs will not affect the game experience other than the visual) in the future, users can choose to buy and experience an architect you like or a designer with a higher evaluation. This may subvert the current economic model of the construction industry, from the traditional client-bid-commission model to a platform model, that is, the museum provides authentic exhibits and spaces, and different architects can design virtual experiences and augmented spaces for this. Visitors can have more choices (Fig.7.8).

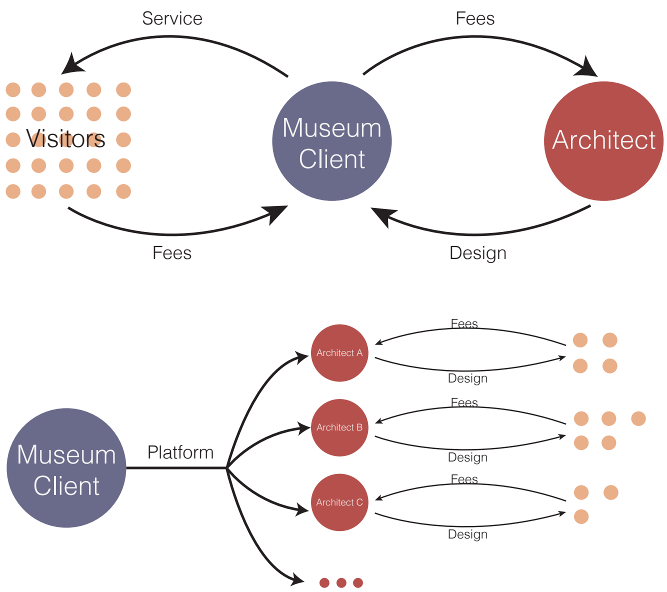


Fig.7.8: Architects role diagram: traditional mode (up) and future mode (down)
Source: Made by author

7.3.3 Redifining Aesthetics of Representation in Architecture

The topic of aesthetics in architecture has a long history. Ancient Greek and Roman architecture highly respected the beauty of the human body, emphasized measurement and order harmony, which fully reflected the aesthetic taste and ideals of the people at that time. Hegel's discussion of the whole meaning and fundamental purpose of architectural aesthetic is to explain that "beauty is the perceptual manifestation of ideas". With the rise of modernism and postmodernism, architectural aesthetics has also aroused many topics of discussion. Regardless of the theory or doctrine, the logical starting point of the study of architectural aesthetics should be the aesthetic activity of people on architecture. People's aesthetic activity of architecture is essentially a value activity, and architectural beauty is a value generated or formed in this activity. That is to say, architectural beauty is a value derived from the aesthetic nature of architecture and human aesthetic needs in architectural aesthetic activities. Architectural beauty is not prefabricated, but generated. The innovation of new media and new technology will always bring about the innovation of aesthetic perception. This innovation not only stays in the performance dimension, but also brings new architectural value. As mentioned above, the value of architecture has experiential value in addition to performance value. This experience has been transformed from a passive way under the guidance of virtual technology into an active way with interaction as the core. The change of aesthetic value will redefine architectural aesthetics. Interaction and experience give architectural aesthetics more possibilities and creativity. Digital media and art can transform the representation of architecture from static to dynamic, and this dynamic can even transcend architectural structure and physical limitations. And the aesthetic value and new aesthetic system behind it are more worthy for architects to think and explore.

7.4 Reshaping Architectual and Urban Space

In the future, under the impact of virutal vision technologies, architectural shape or form might be more suitable for experiencing virtual space and augmented space. including new materials, new interaction logic, changing human scale and the way people interact with space will redefine the spatial morphology changes under the new technology. New space with new experience through virtual vision technologiew will redefine the future museum space. In order to better understand the impact of virtual technology and enhanced elements on indoor space, architectural space and urban space, I defined this reshaping in four different dimensions based on the type of virtual element and its proportion in the real space. The relationship and brief description of the four levels are shown in the figure below. (Fig.7.9)

	Level1	Level2	Level3	Level4
Interior Scale	Floating Info.	Virtual Furniture Augmented Exhibits Preview Unbuilt	Customized Furniture Interactive Space	Customized Interior Impossible Space
Urban Scale	Floating Info. Real-time navigation	Virtual Landscape Augmented Exhibits Preview Unbuilt	In-depth Environment Changes Interactive Space	Customized Architecture Impossible Space New Architectual Vocabulary

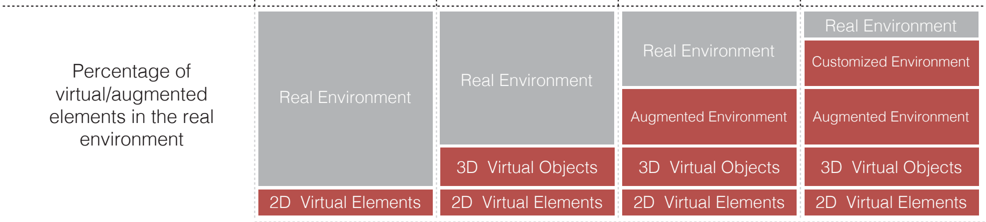


Fig.7.9: Four leves of reshaping in architecutural and urban level
Source: Made by author

Level1: Floating 2D information

As the first level of augmented space, virtual objects occupy a very low proportion in real space, and they are presented to users in the form of two-dimensional information. Two-dimensional agumented information can give users some information supplements. Compared with the traditional space, by reading the floating information in the enhanced space, users can obtain some information more quickly and accurately.

From the perspective of architecture and interiors, floating information can provide more readable content. For example, in the exhibition hall, visitors

QR Code1: Level1-Augmented Space in Museum Demo
https://vimeo.com/475639181

QR Code2: Level1-Augmented Space in Museum Prototype
https://vimeo.com/475646959

can replace the text description of the artwork with enhanced information. I developed a small prototype software for this purpose. The principle of the software is very simple. It can display floating enhanced information by identifying specific objects. As shown in the figure below (Fig.7.10), users can use a tablet to get an explanation of the artwork instead of a small text board. (Video experience clips can scan QR Code1) Furthermore, this kind of explanation can be more interesting and interactive. When the user clicks on the explanation on the screen, the user can get more diverse content, including more detailed information, evaluation of the work,etc. For the video of the concept prototype, please refer to QR Code2.

Extending this two-dimensional floating information to the urban domain, we can find that it will bring more convenience. Especially when the floating information is combined with the commercial field, it will bring some interesting attempts. For example, you can learn about the vacant parking spaces of the parking lot in real time through floating information; detect the user ratings of various businesses in real time in the commercial block; learn about the availability of hotels

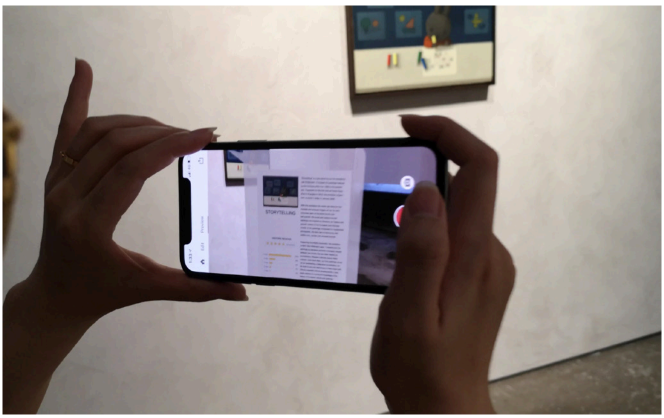


Fig.7.10: Demo Photo and Prototype Photo of Level1 in interior scale
Source: Made by Author

and so on. Finally, the positioning and route planning of urban functions are completed in the navigation system customized by AR. The image below (Fig.7.11) is a small demo of the restaurant rating we have completed. In a prosperous commercial area, users can instantly obtain information and reviews of stores and restaurants through Application, which can better help users make choices. (Please scan QRCode3 and QRCode4 for complete video).

QR Code3: Level1-Augmented Space in Urban Demo
https://vimeo.com/475645581

QR Code4: Level1-Augmented Space in Urban Prototype
https://vimeo.com/468894556

Level2: 3D Virtual Elements

Compared with the first level, this level begins to add three-dimensional virtual objects. Compared with the basic information of simple text and two-dimensional graphics, the intervention of three-dimensional virtual objects greatly enriches the content of the enhanced space. Augmented three-dimensional objects can enhance the architectural space and urban environment in many ways, such as augmented furniture, augmented exhibitions, and augmented landscape installations. At this level, three-dimensional virtual objects can only allow users to interact with simple operations (such as moving, rotating, zooming, etc.), and virtual objects still use visual transmission as

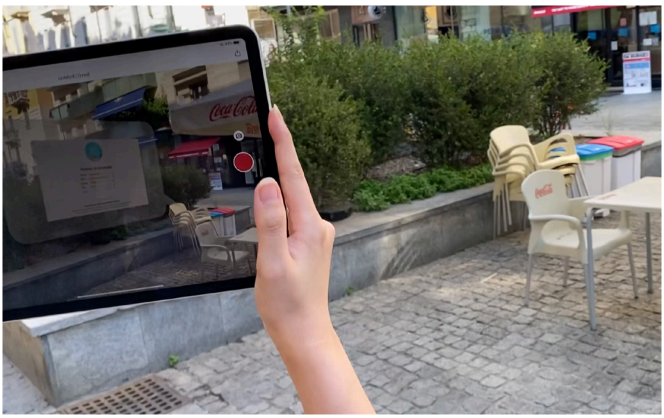


Fig.7.11: Demo Photo and Prototype Photo of Level1 in urban scale
Source: Made by Author

their basic interactive attribute.

In terms of interior design and architectural design, the second-level augmented space gives users more practicality and interest. The introduction of virtual three-dimensional objects in augmented space can be used as a design visualization tool to intervene in interior design and architectural design more intuitively. Users can observe the state of unbuilt objects in space in an immersive manner through screens, glasses or other devices, which simplifies the design process and give non-professional users more to participate in the design process in a more realistic way. As shown in the figure below (Fig.7.12), the user can see the virtual "chair" generated in the real space through the mobile application. Whether from a design or commercial point of view, this level of augmented space can be well accepted and used by the public.

From the perspective of the urban scale, virtual objects at this level are more likely to be presented to the audience as virtual landscapes, virtual installations or virtual artworks. For artists and architects, they can try to create some new forms of art and space through

Fig.7.12: Demo Photo and Prototype Photo of Level2 in interior scale
Source: Made by Author

AR and VR. At this level, urban space will become a canvas for new art. Virtual three-dimensional objects and augmented spaces have more space in the urban scale to show their own charm. Since virtual objects are not restricted by real physical spaces, new spatial art forms will produce more interesting designs and artistry. Art installations and landscapes with augmented objects as the main way of experience are currently seen in museums, such as "Invasive Species" (Fig.7.13). In the future, this art form will be extended to urban spaces, and augmented landscape and virtual art will appear in various scenes in the city in a more immersive and exploratory form. The picture below (Fig.7.14) is a demostration I did in an urban space. Through the tablet, users can see the designed virtual device appearing in the garden.

Fig.7.13: “Invasive Species”, 2017, Perez Art Museum PAMM

Level3: Interactive and Customized Space

As the virtual objects further increase in the real space, the third level of the enhanced space also begins to gradually appear. At this level, virtual objects are no longer visual and simple interactions, and more complex interaction behaviors begin to intervene. The rich interaction mode will also make

Fig.7.14: Demo Photo Photo of Level2 in urban scale
Source: Made by Author

the augmented space have more experience and fun similar to the game. This interaction mode is not only passive, but also presents different states due to different feedbacks from different users. In other words, the virtual object is not fixed in the augmented space, but will change with the user's behavior and interaction. The augmented space has also evolved into a communicative interaction space. This kind of interaction will also evolve into a customized space, and virtual objects will change according to the different attributes of users.

On the interior and architectural scales, this level of augmented space can more effectively mobilize the enthusiasm of participants, and encourage users to participate in the design and provide timely feedback. It seems that in the future, the most likely indoor space to use this level is the exhibition space. As a natural avant-garde art and new technology practice place, the museum is the best place to experience new types of space. The following figure (Fig.7.15) describes this phenomenon in the form of illustrations. For the same art exhibits, a space customized for children is a more interesting and simple animation; for professionals, customized spaces will be more specific to the details

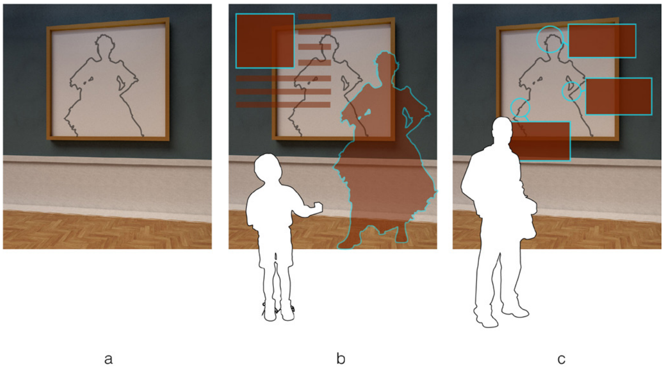


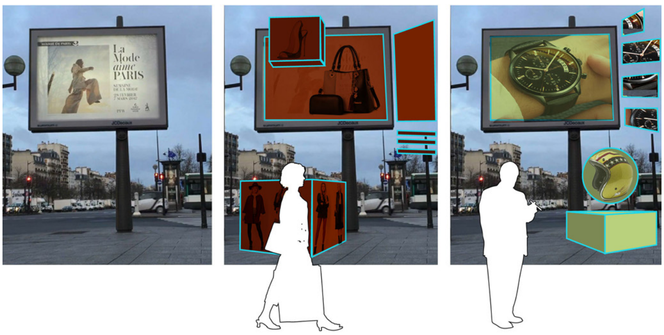
Fig.7.15: Diagram of customized space of Level3 in interior scale
a: Originial Space
b: Customized Space for Children
c: Customized Space for Adult
Source: Made by Author

of the artwork through a deeper interpretation.

In urban space, the third level of augmented space may be the most promising business model in the future, especially in commercial public spaces, where customized urban scenes can give users the best shopping experience based on the support of big data. The simplest typical case is billboards in future cities. Today's billboards can be seen everywhere in urban commercial spaces, and the content of these billboards is the same for everyone. In the future, this situation will be the first to change. In an interview with Arch.Xia, he also mentioned the need to "respect the commercial value brought by AR" (see Appendix 2 for details). The figure below (Fig.7.16) shows a conceptual diagram. The urban environment where the billboard is located will change according to different users. This change is not limited to the change of the billboard content. The augmented environment and virtual objects will also be different.

Level4: New Architectural Vocabulary

The fourth-level augmented space is currently just a hypothesis and concept prototype of the future city and architectural space. Conceptually, this level of



a b c

Fig.7.16: Diagram of customized space of Level3 in urban scale
a: Originial Space
b: Customized Space for Group1
c: Customized Space for Group2
Source: Made by Author

space can be understood as the third-level continuous form, which is not only content but also experience and updates. When using urban or architectural spaces, the virtual content generated by augmented reality can change instantly according to the user's behavior. This concept is similar to the Hyper-Reality[1] proposed by Keiichi Matsuda (Fig.7.17). In his description, the possible forms of the future city will be gradually intertwined with physical and virtual reality. Technology as a link between interaction and experience will provide an unprecedented spatial form and architectural vocabulary. This is also a form of display of the fourth-level augmented space in the future.

1. Hyper-Reality (total runtime approx 6 minutes) is a concept film by Keiichi Matsuda. It presents a provocative and kaleidoscopic new vision of the future, where physical and virtual realities have merged, and the city is saturated in media.

In the future, a space dedicated to experiencing the virtual environment may be born. This space does not require complex building materials and spatial forms but instead is replaced by various precise sensing systems and devices. From a technical point of view, this can help the augmented space to understand the user's behaviour in the virtual experience more accurately and make corresponding feedback. The advancement and popularization of technology will make the augmented space easier to be accepted

Fig.7.17: Hyper-Reality
Source: http://hyper-reality.co/

by more people, which will also prompt the relevant departments to formulate some standardized augmented space production processes.

In the hypothetical augmented space, the virtual elements and the physical building structure together constitute the texture and form of the city. The boundaries between public and private spaces have begun to blur, and the boundaries between interiors, buildings and cities have also begun to become different. The definition and vocabulary of space need to be redefined. The physical structure does not necessarily distinguish the boundaries of space. In the future, virtual elements will also have the same architectural value as the physical structure. Architects and designers need to re-face these architectural elements. They are not only facing traditional building materials such as concrete and glass. They need to think more about how to use virtual elements as building materials to enrich the space and experience form. Whether it is augmented space or physical space, the experience and the creation of space are what architects need more intervention. At present, many virtual environments are created by non-architects, which also means that more involvement of architects in the design of augmented spaces helps to enhance the user experience from the spatial level.

7.5 Conclusion

Every new technological change will trigger rapid changes in society and culture, not only for productivity and production methods, but also for people's cultural needs and lifestyle. As the best starting point for exploring urban culture, museums not only need to improve the traditional collection and display functions, but also need to assume a new role as a symbol of the city. In the digital age, people have more and more channels to obtain information. Even at home, they can enjoy various artworks through the Internet and VR glasses. The value and importance of museums are also facing challenges. Museums have to meet increasingly scarce financial support and increasingly brutal market competition. The museum's development strategy has changed from focusing on exhibits to concentrate on the visitor experience. Building a museum brand, actively participating in market competition, and developing new exhibition models has become an effective and sustainable development strategy. In the process of museum transformation and development, the key to reversing the vicious circle is to attract the attention of visitors. The development of Internet technology requires modern museums to have a scientific positioning of the needs of society and the museum itself, and establish the user experience as the core strategic goals.

Compared with other cultural institutions, museums have rich cultural heritage resources. Therefore, authenticity has become the essential value of museums. Paying attention to the authenticity of the exhibition experience has become the primary means for museums to achieve differentiation and participate in market competition. Carefully weigh the advantages and disadvantages of museums, fully consider the demands of designers and visitors, correctly treat the relationship among visitors, exhibits and space, and adopt appropriate methods to play the role of creative and experience authenticity will be the right direction for future museums to respond to the rise of digital space. Digital architectural space does not mean the demise of physical buildings; on the contrary, it can bring new spatial forms and experiences to traditional museum spaces. Facing the impact of shared culture and the Internet era, museums should be brave enough to face challenges and transform their own space into an experimental site where new technologies and traditional culture are intertwined. Augmented space is the best bond between them.

As a new form of space based on virtual vision technology, augmented space and augmented exhibits have begun to be used in museums around the world. With the maturity and popularity of this technology, museum spaces and exhibition methods have begun to change. This change can be summarized from static to immersive, that is, exhibits no longer exist in the museum space in a static and passive form, but creates an immersive experience mode through interaction based on virtual visual technology.

AR and VR, as the best tools and platforms for experiencing virtual vision technology, give designers and architects more possibilities. Compared with traditional design tools and platforms, AR and VR have only 50 years of history, and it has only been nearly 10 years since they have been put into market applications. New tools and new platforms provide more possibilities and give designers an unprecedented creative experience. With the advancement and popularization of technology, AR and VR have also begun to emerge in many aspects. In the field of architecture and exhibition, virtual visual technology can restore and archive cultural heritage through digital technology; it can introduce exhibits in a more immersive way; it can also create "impossible spaces" that are not restricted by physical conditions. The enormous richness of architectural functions and space types will give architects more opportunities and challenges in the future. Function and form are unavoidable topics in architecture and urban space, and the birth and popularity of augmented space have revolutionized both concepts. New media and the Internet define "interaction" as the most essential feature in the digital age. In the future, customized spaces and enhanced environments will be closely related to the real space of our lives. The upgrade of function and form will give architects more thinking. Returning creativity to the essence of design and enhancing the user's experience in the space are what future architects need to take seriously in the face of the revolution triggered by digital technology.

This also reiterates that architects need to pay attention to the application of user experience in architectural space. The research on user experience in space design is still being explored. Although the design theory and framework of product design cannot be fully applied in architectural design, its concepts and research on user experience are of great significance in the design of architectural space. In particular, museum space is a type of space mainly oriented on visual experience. Coupled with technological means, virtual reality and augmented reality will use the means or tools of applications and digital products to evolve the museum space to a new dimension. Under the dual role of combining space design and digital products, the importance of user experience is even more important for architects. It is feasible to use experience-driven design approach as in modern museum space design. Based on the extensive use of virtual and digital technologies in modern museums. It is foreseeable that digital products, especially augmented exhibits and virtual experiences, will gradually increase in future museums. The core of this digital product can rely on the experience-driven design approach. And from a spatial perspective, this design approach can still play a role. Pay more attention to the visitors' personal attitude in the museum space. From the perspective of experience, it is supplemented by technical means and augmented exhibits. It is one of the best choices for a contemporary museum to enhance self-attraction and contribute social value.

Driven by virtual vision technology, the relationship between exhibits, space and visitors in the museum has been redefined. If the concept of the future museum is expanded to an urban scale, it can be foreseen that in the future, the spatial environment in the city, the relationship between virtual elements and residents will also change accordingly. The city may be full of augmented spaces at all levels. And augmented space also means the blurring of the boundary between private space and public space. Customized enhanced space allows users to experience the virtual environment more specifically. The future museum and future city under this hypothetical environment also make new requirements for the role of architects, and even change the production logic and production relations. The new augmented spatial form and aesthetic cognition in the digital age will eventually bring architectural design back to creativity as the core and user experience as the drive.

CHAPTER 8

CONCLUSION

The museum, undertaking to demonstrate the starting point of a particular country and regional civilization, is a country or a region's "cultural genes". ICOM(International Council of Museums)'s definition of a museum is: *"A museum is a non-profit making, permanent institution in the service of societyand of its development, and open to the public, which acquires,conserves, researches, communicates and exhibits, for purposesof study, education and enjoyment, material evidence of people and their environment."*[1] Therefore, the museum's design is crucial to embody the level of the museum and plays an essential role in the museum undertaking. The museum, as a social public service agency, is an essential part of social culture. Its preservation and study of the antiques aim to contribute to the harmonious development of society and serve the

Development of the Museum Definition according to ICOM Statutes (1946–2001), available at: http://icom.museum/hist_def_eng.html.

social public. Exhibitions are the most effective spiritual and cultural products provided to the society by the museum, and it is an important means of social service, particularly the application of the novel exhibition methods in modern museum brought by the influence of new technological revolution. Museums have always played a crucial role in narrating identities, and have been involved in their production and construction.

The rapid rise of the internet and digital technology has put us in the midst of a technological revolution. This has changed the way we interact with the world and our mode of perception. Virtual visual technologies, represented by AR and VR, have given us more diverse ways of viewing. These technological changes bring with them new opportunities and challenges. Revolutionary ways of display and interaction are placing new demands on the museum space of the future. Museum visitors in the digital age may be no longer satisfied with the traditional, passive approach to exhibitions and maybe instead of looking for more active participation(Hooper-Greenhill, 2007).

The COVID epidemic that swept the world in 2020 has led to a rapid spread of conflicts and contradictions arising from this change and has affected every aspect of our lives, from our personal lives to how we communicate, from our working patterns to our design processes. Museums are no exception, and cultural organisations have been hit quite hard. Museums have been deeply affected by this crisis, both on an economic and socio-cultural level. However, the crisis has also given impetus to the significant innovations already underway, particularly the increasing focus on digitalisation and the creation of new forms of cultural experience and communication. In this context, museums should embrace and lead this change. We need to rethink the relationship among museum spaces, exhibits and visitors. Experiment with new models of cultural hybridity and reaffirm the fundamental value of a sustainable future for museums. At the same time, we need to promote new cultural and spatial creative potentials as a way to drive the recovery and development of museum spaces in the post-epidemic era.

Against this background, the research will focus on the impact of virtual visual technologies (mainly AR and VR) in museums and exhibition spaces. With the addition of virtual technologies, exhibition spaces will no longer be passively observed by visitors, but will be transformed into augmented exhibits that engage with visitors in a real-world interactive logic. The visitor's experience in this augmented exhibition is intangible and can be described as a virtual experience. How augmented exhibits and virtual experiences are (or will be) transforming museum spaces in the post-epidemic era of the Internet, how they will define the relationship between space, exhibit and visitor, and what changes these will bring to museum space and display design, are all important questions for this thesis. To address these questions, the purposes of the research are: Designing a experience-based conceptual model for the use of immersive experience design through AR and VR; Defining the emerging AR and VR in the field of museum design; Defining the key parameters in augmented exhibition; Discussing the value and trends of physical museums under the influence of virtual experiences; Defining the reshaping level based on the type of virtual element and its proportion in the real space.

After a series of analysis and research, including questionnaires, fieldwork, literature review, prototype testing and numerous case studies, it became clear that from static exhibition space to immersive experience is the trend of the future exhibition space. Based on the development of visual technology simulation, Virtual vision technologies are taking the immersive experience to a new level. Virtual experience and augmented exhibition will become the main way of immersive experience in museum spaces. Architects and designers can more easily to create an immersive experience with these new tools. Visitors are also more likely to use and accept new technologies.

Specific to the particular technology area, AR and VR, this study provides a more in-depth exploration of these two specific technological tools, including a history, applications and a comparative study of them in specific contexts. As an emerging virtual vision technology, AR and VR have produced remarkable progress and development since their birth in the 1950s. In a period of several decades, it has gradually entered the stage of popularization and application from the concept and experiment stage. Under the influence of the market economy, new technologies and equipment have become popular among users. This influence also affects museums and exhibition spaces. Although VR and AR history is short-lived, its impact on museums and exhibition space will be profound. VR and AR's future development's positive attitude is one of the conditions that promote the continuous evolution of virtual technology in real space. In several typical museums (science and technology museums, art museums, site museums), virtual technology creates new spaces of interaction and immersion in different attributes that activate the museum and give users a better experience. The advantages offered by these enhanced exhibitions in museum spaces can be summarised in three categories: presenting additional information, building unbuildable spaces and creating new experiences.

Further research inevitably leads to a comparative study of digital technologies and topics related to user experience. From a particular perspective, architectural design can be understood as a mega product design based on physics and space (including real and virtual space). Space is both the language of architectural design and a medium which allows an intangible interaction between users and structures. Furthermore, a building, the result of architectural design, can be seen as a tangible digital product. In fact, in the context of the digital age and the Internet of things, there is a crossover between the fields of architecture and digital product design, especially in terms of user experience. This kind of interdisciplinary research on design and user experience between architecture under the influence of virtual vision technologies and digital products is of far-reaching significance. By integrating and summarising "Elements of User Experience" proposed by Jesse James Garrett (2000) and "four experience realms" defined by Pine and Gilmore (1999), and drawing on the characteristics of virtual visual technologies and theories related to museum spaces, five elements of experience-driven museum space in a digital environment are defined, namely visitors personas, time, interactivity, immersion and significance. And on this basis, proposal an experience-driven approach for museum space design in the digital era. Based on the extensive use of virtual and digital technologies in modern museums. It is foreseeable that digital products, especially augmented exhibits and virtual experiences, will gradually increase in future museums. The core of this digital product can rely on the experience-driven design approach. And from a spatial perspective, this design approach can still play a role. Pay more attention to the visitors' personal attitude in the museum space. From the perspective of experience, it is supplemented by technical means and augmented exhibits. It is one of the best choices for a contemporary museum to enhance self-attraction and contribute social value.

With the evolution of digital models, the number of interaction methods has gradually increased, and digital exhibits will bring some new different experiences. Despite the inherent property of mechanical reproduction, digital exhibits may be observed ubiquitously. While museum space provides authentic space with experiential value, the organic combination of museum space and digital products will upgrade exhibition space. While visitors interact with the exhibits, these behaviours, cognitions, feelings and experiences together upgrade the museum exhibition space and turn the exhibition space into an interactive space. As visitors, their curiosity is actively mobilized in the museum space. Today, we live in an era filled with digital elements. Cell phones, computers and smart devices permeate all corners of our surroundings. Diverse digital media and interaction methods have redefined the logical relationship between the visitors and the digital exhibits, and visitors have increasingly demanded interactive experiences. The interactive way of "seeing" in the museum space is slightly behind in the eyes of the times' development. AR and VR dissolve the sense of boundary between the virtual world and the real world, which provides potential possibilities for creating immersive interactive spaces. The change of space and the possibility of interaction have given the architect an experiment site for design talents. It is also because the means and tools for creating space are being enriched, and the participants in space experience changes in the form of space. This is helpful for the increase of participation and attractiveness of public space such as museums.

When virtual elements are injected into real museum spaces, the critical question that inevitably comes up is how to define the real and the virtual, and whether physical museums still have any value. In the digital age, people have an increasing number of channels to access information. Even at home, they can enjoy various works of art via the Internet and VR glasses (this approach that seems to have become more popular during the epidemic). The value and importance of museums are also being challenged. Museums must meet increasingly scarce financial support and increasingly brutal market competition. Museums' development strategies have shifted from a focus on exhibitions to a focus on the visitor experience. Admittedly, the internet and virtual visual technologies offer many conveniences. However, authenticity and experiential value dictate that physical museums will not be completely replaced by virtualisation.

Authenticity is a central pillar of museums. The authenticity of the art (including the building itself) and the exhibits is a key reason museums can continue attracting visitors. Although the "aura" of the artwork is fading in the age of mechanical reproduction (Benjamin, 1936), it will not disappear completely. Conversely, as a new form of art designed to be used, the virtual element also has an authentic "aura". This means that the museum space is beginning to evolve from a worship value to an experience value. Only by carrying forward the place value and cultural value in the original space as much as possible can the virtual elements be integrated into the place in a better way. This contrast and immersion between virtual and reality will bring a new experience in the digital age.

Based on the authentic architectural space, and inspired by virtual elements created by digital technology, the real space and the virtual environment are closely and creatively integrated, so that a new chemical reaction occurs. The augmented space created by combining cultural background and scene interaction is the charm and value of virtual experience authenticity. Numerous case studies and pilot project confirm that augmented exhibitions cannot fully replace physical museums. Even *Space Popular*[1], who specialises in the creation of virtual spaces, believes that *"Virtual space does not replace the physical, it adds a new layer on top."* There is no shortage of examples of virtual reality in case studies such as "*Rhomaleosaurus: Back to Life in Virtual Reality*", where visitors can enjoy the virtual content without being in a physical museum, but the result is a fundamentally different experience to that of a visitor who experiences both (real and augmented) in the real museum space. Instead, the VR experience has piqued visitors' interest in going to the real museum.

1. Space Popular is directed by Lara Lesmes and Fredrik Hellberg, both graduates from the Architectural Association in London (2011). They founded the practice in Bangkok (2013) and have been based in London since 2016. Space Popular creates spaces, objects, and events in both physical and virtual space, concentrating on how the two realms will blend together in the near future. The studio has completed buildings, exhibitions, public artworks, furniture collections, and interiors across Asia and Europe, as well as virtual architecture in the Immersive Internet.

In order to avoid the creation of pan-entertainment in museums as a result of excessive virtual and interactive elements, virtual information should be constructed through good cooperation between cultural heritage experts (museum curators, historians, archaeologists, etc.) and information science experts to ensure the core functions of the museum. The display value of exhibits and the authenticity of place and experience that museum spaces provide remain essential supports for museums in the digital age. This means that in the future, the collaboration of museology, anthropology, social sciences and technology will be widely involved in museum design.

As with the global epidemic in 2020, there is so much uncertainty about the future, but this research still hypothesises and fantasises about museums' future and even future cities, based on virtual vision technology. In the future, under the impact of these technologies, architectural shape or form might be more suitable for experiencing virtual space and augmented space. Including new materials, new interaction logic, changing the human scale, and the way people interact with space will redefine the spatial morphology changes under the new technology. New space with new experience through virtual vision technologies may redefine the future museum space. Through defining the four different dimensions based on the type of virtual element and its proportion in the real space for reshaping architectural and urban space, a new vision of the world may emerge in the future.

As customised and augmented spaces become popular, architects' roles and responsibilities will change accordingly, and even new business models will emerge. The aesthetic representation of architecture and space will once again be revolutionised and redefined. In the hypothetical augmented space, the virtual elements and the physical building structure together constitute the city's texture and form. The boundaries between public and private spaces have begun to blur, and the boundaries between interiors, buildings and cities have also begun to become different. The definition and vocabulary of space need to be redefined. The physical structure does not necessarily distinguish the boundaries of space. In the future, virtual elements will also have the same architectural value as the physical structure. Architects and designers need to re-face these architectural elements. They are not only facing traditional building materials such as concrete and glass. They need to think more about how to use virtual elements as building materials to enrich the space and experience form. Whether it is augmented space or physical space, experience and space creation are what architects need to propose more intervention. And the interaction between construction and virtuality may offer more and more sparks for critical discussion in architecture.

It can be foreseen that in the future, the city's spatial environment, the relationship between virtual elements and residents may also change accordingly. The physical city may be full of augmented spaces at all levels. Moreover, augmented space may also mean a gradual blurring of the boundary between private space and public space. Customized enhanced spaces allow users to experience the virtual environment more specifically. In conclusion, whatever the way will represent, the future museums and cities under this hypothetical environment will also need new requirements for architects' role and even change the production logic and production relations. The increases of augmented space will lead to a new understanding of spatial form and aesthetic perception. Technological developments in the digital age will allow the means of representation and design tools to mature and begin to liberate creativity and productivity. The richness of expression, the diversity of experience frameworks and the gradual breaking down of technological barriers will enhance, enrich, and confirm inspiration and creativity as the essence of architectural design, and interaction and user experience as the core driving force in integrating real, augmented, and virtual museums and exhibitions.

APPENDIX 1

Survey and Questionnaire

AR and VR use and experience in the museum

Q1: The frequency of your visit to a museum or exhibition is probably?

A. Less than 1 time per year
B. 1-5 times per year
C. 5-10 times per year
D. 10-20 times per year
E. More than 20 times per year

Q2: The type of museum or exhibition that you most often or most willing to visit is?

A. Art museum
B. Science and technology museum
C. Nature and history museum
D. Site museum
E. General museum
F. Other types

Q3: Do you have a basic understanding of AR and VR?
A. I have never heard of it, I didn't understand
B. I have heard of it, but I have not experienced it.
C. I have heard of it and have experienced it, but the number is not much.
D. I have heard of and experienced many types of AR or VR
E. Have a deep understanding of related fields
F. I am a practitioner in related fields

Q4: Have you seen AR or VR related projects in a museum or exhibition space?
A. Never seen
B. Occasionally seen
C. Many museums can be seen

Q5: What type of museum do you think AR and VR are more suitable for?
A. Art museum
B. Science and technology museum
C. Nature and history museum
D. Site museum
E. General museum
F. Other types

Q6: Which kind of AR or VR you prefer in a museum or exhibition?
A. Head-mounted (helmet, glasses, etc.)
B. Handheld (mobile, tablet, etc.)
C. No need for personal device mode (holographic projection, special screen, etc.)

Q7: Do you prefer to use interactive devices in museums or exhibitions?
A. I don't like interactive devices and exhibits

compared to ordinary exhibits.

B. Same as ordinary exhibits

C. I prefer to use interactive devices compared to ordinary exhibits.

Q8: Your acceptance of non-material virtual (digital) exhibits in the museum is?

A. Not accepted at all

B. No support or no objection

C. Accept and enjoy the virtual (digital) exhibits

Q9: Do you feel that AR and VR will change the viewing experience of the original museum?

A. There will be almost no change

B. There will be some changes

C. There will be a big change

Q10: Do you think that AR and VR will change the space design of the museum?

A. There will be almost no change

B. There will be some changes

C. There will be a big change

Q11: Do you think AR and VR technology will be more used in museums and exhibitions in the future?

A. No

B. Not Sure

C. Yes

Q12: What do you think is the biggest advantage of AR and VR in the museum?

Q13: What do you think is the biggest disadvantage of AR and VR in the museum?

APPENDIX 2

Interview Report

Interview Time: 12, July, 2020
Interview Form: Online dialogue
Interviewee: Arch. Xia Zhongyan, graduated in UCL, currently working on the combination of AR and architecture, a partner of an architecture studio. Project works include "Synesthesia City" in 8th Bi-city biennale of urbanism/architecture(Fig.8.1).

Interview Abstract:
As we know, virtual vision technologies such as AR and VR technologies have begun to be widely used in various scenarios, especially in museums and exhibition spaces. Arch. Xia Zhongyan, as the forerunner, combined the virtual technology experience with the exhibition space and achieved success. Based on his background as an architect and his AR projects in multiple exhibition spaces, I decided to conduct an interview with him about AR

and architectural space. In this interview report, we can get some inspiration about AR, museum and urban such as How does AR technology become a choice for these interesting projects in museums? And how does AR technology combine virtual elements with real spaces in exhibitions? What changes and effects of this new technology will bring to exhibition spaces, architecture, and even cities.

Interview Content:
Question(Q): When was your first contact with AR and VR, what was your first impression?
Answer(A): *The first contact with AR should be the film named Hyper-Reality of Keiichi Matsuda[1] on the British campus. The first impression is that I still felt that this thing was very playful and dramatic, and even some light pollution.*

Q: Do you think AR can become a productivity tool in the future? And how often do you use AR daily?
A: AR will become a part of future life. My personal opinion is that AR will be combined with existing technology and equipment. For example, this year's apple conference, AR glasses will become part of the presentation of AR content, but not all. I am currently exposed to AR every day due to development needs, but most of the domestic AR is currently a 2b(to business) project, and due to equipment limitations, few 2c(to client) projects are currently successful.

Q: So do you think AR may be more than just a tool? Or that AR is not just a tool and a form of display, is it possible to become a phenomenon?
A: This is the blockchain technology I mentioned. AR's current situation only solves part of the presentation problem, so it is limited to some small projects within a fixed range. But when AR devices and 5G networks

are popularized, it will be another state. Blockchain technology will solve the database problem, AR will solve the data representation problem, these two disruptive technologies will definitely change the state of our lives. For example, a simple example, in 2019, advertising in elevators in mainland China, this industry is currently worth 22billion RMB(2,7billion Euro). If the entire Shanghai area is added to AR technology, the industry will do very large, with a value of nearly ten trillion.

Q: For you, what kind of new ideas can the virtual visual technology of AR VR bring to the audience in the exhibition space?

A: My personal point of view is that I still have to mention the limitations of equipment and models. A considerable number of users' mobile phone computing power and SDK and hardware do not meet the ar/vr rendering standard, and mobile phones are not necessarily the best experience equipment. In some of our specific 2b projects, the equipment is generally prepared in advance for on-site use. In addition, because this industry is relatively new, sometimes it only solves the presentation problem. The problem of controlling the quality of the content is not too good to solve. To put it simply, it is ugly, because at present, It's the technical staff who are doing the design.

Q: In other words, designers and architects should be more involved in this aspect, whether from an aesthetic or interactive perspective?

A: I think it is necessary. When an industry begins to mature, more people should be added, but it needs to wait for a more clear profit method. I think not only to see the aesthetic value, but also to see the value of advertising, promotion, channels, etc.

Q: Even business value may be more preferred?
A: Yes, and these must definitely be supervised by strong government agencies. Considering that the running cost of a server is too high, blockchain technology can be appropriately introduced to introduce small and medium-sized businesses.

Q: Is it similar to the billboards on the street, this can be customized according to the personal data of big data, everyone will see different content through the filtering of AR devices?
A: Yes

Q: Then expand this idea a bit, the facade form and aesthetics of the building may also be partially replaced by AR?
A: This is definitely a new collection of technologies, and the impact on architecture is likely to be revolutionary, but it may take a decade or two to achieve. Somehow it can be simply understood as a new skin design for architecture. But it's not only just the shape, it's actually permeating the whole place.

Q: In addition to the reasons you mentioned earlier, is it currently the most advanced in museums and exhibitions?
A: Sure, it is used more in small scenes such as exhibition space

Q:Speaking of this exhibition space, you also have a project application in the exhibition space before. For you, how to judge whether a project or an exhibition can use AR, or why did you choose to use AR to complete this project in the design process?
A: It can be judged from the value, that is, what added

value AR can bring to this project. From the content display to the commercial purpose, there will be certain judgment standards. The content is more focused on delivering more information in the time of the unit, while the commercial takes into account entertainment and novelty

Q: Generally speaking, do you give the concept of AR to the owner, or does the owner propose to use AR, and you implement it?
A: Generally, the latter is more, the former may take time to understand AR for some clients.

Q: What role do we play as an architect in this AR environment?
A: I'm hard to say, but I personally have an attitude that is willing to accept and even devote myself to this cause. The architect himself has a high affinity with architectural space and urban planning, and if he knows some technology, it will definitely hit a new spark. And AR will be incorporated into the national norms in the future, and when formulating AR space application standards, the architect itself can provide advice and reference as a scholar.

Q: What about VR, do you think VR is currently at a disadvantage compared to AR?
A: I think AR provides a bridge between the real world and VR. The two do not conflict. VR is the real immersive content.

Q: As the real space of the AR background, what conditions do you think will provide AR creators?
A: I think the first thing to solve is the modeling and transmission of the digital city model. The second is that AR is augmented reality. The life after AR is also the life after augmentation, not completely new. The

original status quo and lifestyle must be considered.

Q: The final question, the city under the influence of AR, we may have an idea, then, whether there are some potential hidden dangers or problems?

A: At the surface, the immersion of ar will cause more traffic accidents. In the deeper level, because of the overflow of information, it is necessary to strengthen supervision. It is a new challenge to the administrative model and cost.

Q: Do you have anything to add? Such as AR and architecture, AR and city?

A: See more how to achieve commercial value, it should be the best respect for AR, because AR itself is a technical tool.

Summary:

After an in-depth exchange with Arch. Xia, we can find that although AR has achieved wide recognition and user participation, it still maintains a sense of freshness in many exhibition projects and venues, especially for curators and clients. For most of clients, they are willing to introduce this kind of virtual visual technology in the exhibition project and try it out, and the result is conspicuous. The user's participation and entertainment are obviously improved, which injects lots of vitality into the static exhibition.

Arch.Xia is optimistic about the impact of future museum, exhibition and urban design under AR technology, and it also provides a vision for the new form that virtual visual technology can provide to cities and buildings. In his description, future cities will have great development prospects based on blockchain technology and 5G networks or even more advanced technologies, and they may even present certain scenarios of cyberpunk.

At the same time, Arch. Xia also mentioned the value of AR in architecture. Cites under the action of AR will evolve into a new urban framework. And this new architectural framework will generate new values. Augmented architecture under visual technology will develop different culture and aesthetic value. Its commercial value and government policy support are also important elements that cannot be ignored.

REFERENCES

Museums:

Art Gallery of Ontario
317 Dundas St W, Toronto, ON M5T 1G4, Canada
https://ago.ca/

ArtScience Museum
6 Bayfront Ave, Singapore
https://zh.marinabaysands.com/museum.html

Berlin Museum für Naturkunde
Invalidenstraße 43, 10115 Berlin, Germany
https://www.museumfuernaturkunde.berlin/en

Biblioteca Pinacoteca Accademia Ambrosiana
Piazza Pio XI, 2, 20123 Milano MI, Italy
https://www.ambrosiana.it/

Carnegie Museum of Art
4400 Forbes Ave, Pittsburgh, PA 15213, USA
https://cmoa.org/

Casa Batlló
Passeig de Gràcia, 43, 08007 Barcelona, Spain
https://www.casabatllo.es/

Clyfford Still Museum
250 Bannock St, Denver, CO 80204, USA
https://clyffordstillmuseum.org/

Cooper Hewitt, Smithsonian Design Museum
2 East 91st St, New York, NY, 10128, USA
https://www.cooperhewitt.org/

Detroit Institute of Arts
5200 Woodward Ave, Detroit, MI, USA

https://www.dia.org/

Isabella Stewart Gardner Museum
25 Evans Way, Boston, MA 02115, USA
https://www.gardnermuseum.org/

Mataró Museum
Carrer el Carreró, 17, 08301 Mataró, Barcelona, Spain
https://culturamataro.cat/

Mauritshuis
Plein 29, 2511 CS Den Haag, Netherland
https://www.mauritshuis.nl/en/

Micropia
Plantage Kerklaan 38-40, 1018 CZ Amsterdam, Netherland
https://www.micropia.nl/en/

Milwaukee Public Museum
800 W Wells St, Milwaukee, WI 53233, USA
http://www.mpm.edu/

MUDEC - Museo delle Culture
Via Tortona, 56, 20144 Milano MI, Italy
https://www.mudec.it/ita/

MUSE - Museo delle Scienze di Trento
Corso del Lavoro e della Scienza, 3, 38122 Trento TN, Italy
https://www.muse.it/en/

Musée des Plans-Reliefs
Hôtel national des, 129 Rue de Grenelle, 75007 Paris, France
http://www.museedesplansreliefs.culture.fr/

Musée d'Histoire Naturelle de Lille
19 Rue de Bruxelles, 59000 Lille, France
https://mhn.lille.fr/

Museum of Science, Boston
1 Museum Of Science Driveway, Boston, MA 02114, USA
https://www.mos.org/

Museum of the Moving Image
36-01 35th Ave, Queens, NY 11106, USA
http://www.movingimage.us/

National Museum of Singapore
93 Stamford Rd, Singapore
https://www.nhb.gov.sg/nationalmuseum/

National Science and Media Museum
Pictureville, Bradford BD1 1NQ, UK
https://www.scienceandmediamuseum.org.uk/

Natural History Museum
Cromwell Rd, South Kensington, London SW7 5BD, UK
https://www.nhm.ac.uk/

New Museum
235 Bowery, New York, NY 10002, USA
https://www.newmuseum.org/

New York Hall Of Science
47-01 111th St, Queens, NY 11368, USA
https://nysci.org/

Pérez Art Museum Miami
1103 Biscayne Blvd, Miami, FL 33132, USA
https://www.pamm.org/

Putnam Museum and Science Center
1717 W 12th St, Davenport, IA 52804, USA
https://www.putnam.org/

Renwick Gallery of the Smithsonian American Art Museum
1661 Pennsylvania Avenue NW, Washington, DC

20006, USA
https://americanart.si.edu/visit/renwick

Royal Air Force Museum London
Grahame Park Way, London NW9 5LL, UK
https://www.rafmuseum.org.uk/

Science Museum
Exhibition Rd, South Kensington, London SW7 2DD, UK
https://www.sciencemuseum.org.uk/home

The Cleveland Museum of Art
11150 East Blvd, Cleveland, OH 44106, USA
https://www.clevelandart.org/

The Franklin Institute
222 N 20th St, Philadelphia, PA 19103, USA
https://www.fi.edu/

The Metropolitan Museum of Art
1000 5th Ave, New York, NY 10028, USA
https://www.metmuseum.org/

The Morgan Library & Museum
225 Madison Ave, New York, NY 10016, USA
https://www.themorgan.org/

The State Tretyakov Gallery
Lavrushinsky Ln, 10, Moscow, Russia
https://www.tretyakovgallery.ru/en/

Whitney Museum of American Art
99 Gansevoort St, New York, NY 10014, USA
https://whitney.org/

Technologies:

AR Core
https://developers.google.com/ar/

AR Kit
https://developer.apple.com/arkit/

Broadcast AR 2.0
https://www.indestry.com/broadcast-ar/

Google Tango Project
https://atap.google.com/

Hololens
https://www.microsoft.com/en-us/hololens

HTC VIVE
https://www.vive.com/us/

Project Aero
https://www.adobe.com/products/projectaero

Unity 3D
https://unity3d.com/

Unreal
https://www.unrealengine.com/

Xcode
https://developer.apple.com/xcode/

BIBLIOGRAPHY

Adlin, Tamara, and John Pruitt. *The essential persona lifecycle: Your guide to building and using personas.* Morgan Kaufmann, 2010.

Agnello, F., F. Avella, and S. Agnello. "Virtual reality for historical architecture." *International Archives of the Photogrammetry, Remote Sensing & Spatial Information Sciences (*2019).

Allen, Jamie, and Eleonora Lupo. *Representing museum technologies*. Politecnico di Milano, 2012.

Arinze, Emmanuel N. "The role of the museum in society." *Lecture delivered at the National Museum, Georgetown, Guyana* 17 (1999).

Arth, Clemens, et al. "The history of mobile augmented reality." *arXiv preprint arXiv:1505.01319* (2015).

Aurigi, Alessandro, and Fiorella De Cindio, eds. *Augmented urban spaces: articulating the physical and electronic city.* Ashgate Publishing, Ltd., 2008.

Azuma, Ronald T. "A survey of augmented reality." *Presence: Teleoperators & Virtual Environments 6.4* (1997): 355-385.

Banham, Reyner. *Theory and design in the first machine age.* Mit Press, 1980.

Basso Peressut, G. L. and Clelia Pozzi. *Museums in an age of migrations: questions, challenges, perspectives.* EU-Polimi, 2012

Bayer, Herbert. "Fundamentals of exhibition design." *PM (Production Manager)* 6.2 (1939): 17-25.

Bekele, Mafkereseb Kassahun, et al. "A survey of augmented, virtual, and mixed reality for cultural heritage." *Journal on Computing and Cultural Heritage (JOCCH)* 11.2 (2018): 1-36.
Benjamin, Walter. *The work of art in the age of mechanical reproduction*. Penguin UK, 2008.

Berger, John. *Ways of seeing.* Penguin uK, 2008.

Black, Graham. *The engaging museum: Developing museums for visitor involvement.* Psychology Press, 2005.

Bleeding Cool. *"Ubisoft Has Recreated Notre-Dame De Paris In A VR Tour"*. Accessed May 10, 2020. https://bleedingcool.com/games/ubisoft-hasrecreated-notre-dame-de-paris-in-a-vr-tour/

Bostanci, Erkan, Nadia Kanwal, and Adrian F. Clark. "Augmented reality applications for cultural heritage using Kinect." *Human-centric Computing and Information Sciences 5.1* (2015): 1-18.

Boylan, Patrick, ed. *Museums 2000: politics, people, professionals and profit.* Routledge, 2005.

Brewer, J. D. *Ethnography*. Philadephia, 2002.

Burdea, Grigore C., and Philippe Coiffet. *Virtual reality technology*. John Wiley & Sons, 2003.

Cabero-Almenara, Julio, and Julio Barroso-Osuna. "The educational possibilities of Augmented Reality." (2016).

Carrozzino, Marcello, and Massimo Bergamasco. "Beyond virtual museums: Experiencing immersive virtual reality in real museums." J*ournal of Cultural Heritage* 11.4 (2010): 452-458.

Choi, H. S. "The conjugation method of augmented reality in museum exhibition." *International Journal of Smart Home 8.1* (2014): 217-228.

Clark, Laura. "Paintings without Frames: The Role of Augmented Reality in Art Galleries." (2019).

Claudia Malfitano, "Interviews Felice Grodin Presents Miami's'Invasive Species'", Accessed August 19, 2020, https://myartguides.com/interviews/felice-grodin-presents-miamis-invasive-species/

Crysler, C. Greig, Stephen Cairns, and Hilde Heynen, eds. *The SAGE handbook of architectural theory.* Sage, 2012.

Davies, Char. *Osmose: notes on being in immersive virtual space.* Lisse, The Netherlands: Swets & Zeitlinger Publishers, 2002.

Diodato, Roberto. *Estetica del virtuale.* Pearson Italia Spa, 2005.

Dünser, Andreas, et al. "Virtual and augmented reality as spatial ability training tools." *Proceedings of the 7th ACM SIGCHI New Zealand chapter's international conference on Computer-human interaction: design centered HCI*. 2006.

Economou, Maria. "The evaluation of museum multimedia applications: lessons from research." *Museum Management and Curatorship 17.2* (1998): 173-187.

Egenter, Nold. "Otto Friedrich Bollnow's anthropological concept of space." *5th International Congress of the 'International Association for the Semiotics of Space', Hochschule der KYnste Berlin.* 1992.

Ettlinger, Or. "In Search of Architecture in Virtual Space." S*lovenia: University of Ljubljana (2008)*: 64.

Falk, John Howard. "Learning from museums: visitor experiences and the making of meaning/John H. Falk and Lynn D. Dierking." (2018).

Galani, Areti. "Mixed Reality Museum Visits: Using new technologies to support co-visiting for local and remote visitors." *Museological review 10* (2003).

García, Adolfo Muñoz, and Ana Martí Testón. 2018 "Reframing museum experiences with augmented reality to transform museums content into an emotional journey." *In 10th International Conference on Education and New Learning Technology (Palma, 2nd-4th of July, 2018):* conference proceedings. IATED Academy, 2018.

Gilman, Benjamin Ives. "Museum fatigue." *The Scientific Monthly 2.1* (1916): 62-74.

Gilroy, Stephen W., et al. "E-tree: emotionally driven augmented reality art." *Proceedings of the 16th ACM international conference on Multimedia*. 2008.

Gimeno, Jesús, et al. "Combining traditional and indirect augmented reality for indoor crowded environments. A case study on the Casa Batlló museum." Computers & graphics 69 (2017): 92-103.

González, Nora Argelia Aguilera. "How to include augmented reality in descriptive geometry teaching." *Procedia Computer Science* 75 (2015): 250-256.

Hansen, Ann H., and Lena Mossberg. "Consumer immersion: A key to extraordinary experiences." *Handbook on the experience economy.* Edward Elgar Publishing, 2013.

Heilig, Morton L. "Sensorama simulator." U.S. Patent No. 3,050,870. 28 Aug. 1962.

Heilig, Morton Leonard. "El cine del futuro: The cinema of the future." *Presence: Teleoperators & Virtual Environments 1.3* (1992): 279-294.

Hemmerling, Marco, and Luigi Cocchiarella, eds. *Informed Architecture: Computational Strategies in Architectural Design.* Springer, 2017.

Invitto, Sara, et al. "Easy perception lab: Evolution, brain and virtual and augmented reality in museum environment." *International Conference on Augmented and Virtual Reality*. Springer, Cham, 2014.

Janson, Alban, and Florian Tigges. *Fundamental concepts of architecture: The vocabulary of spatial situations.* Walter de Gruyter, 2014.

Kato, Hirokazu. "Inside ARToolKit." *1st IEEE International Workshop on Augmented Reality Toolkit.* 2007.

Kaufmann, Hannes, and Dieter Schmalstieg. "Mathematics and geometry education with collaborative augmented reality." *ACM SIGGRAPH 2002 conference abstracts and applications.* 2002.

Küsel, Udo. “Open-air Museum versus Site Museum”SAMAB 18 (5), (1989): 183–185.

Latour, Bruno. "The Berlin key or how to do words with things." *Matter, materiality and modern culture* (2000): 10-21.

Lévy, Pierre. "Il virtuale (1995), tr. it." *Raffaello Cortina Editore, Milano* (1997).

Lucas, Ray. *Research methods for architecture. London: Laurence King Publishing*, 2016.

Mackay, Wendy E. "Augmented reality: linking real and virtual worlds: a new paradigm for interacting with computers." *Proceedings of the working conference on Advanced visual interfaces.* 1998.

Manovich, Lev. "The language of new media. Massachusetts." *MIT Press, http://faculty. georgetown. edu/irvinem/theory/Manovich-LangNewMedia-excerpt. pdf., Erişim tarihi 1* (2001): 2018.

Manovich, Lev. "The poetics of augmented space." *Visual communication 5.2* (2006): 219-240.

Martínez, Bibiana, et al. "TinajAR: an edutainment augmented reality mirror for the dissemination and reinterpretation of cultural heritage." *Multimodal Technologies and Interaction 2.2* (2018): 33.

Mase, Kenji, Rieko Kadobayashi, and Ryohei Nakatsu. "Meta-museum: A supportive augmented-reality environment for knowledge sharing." *ATR workshop on social agents: humans and machines.* 1996.

Matsuda, Keichii. "Domesti/city—The dislocated home in augmented space." *Master of Architecture Thesis* (2010).

Maurice Benayoun. *"Interactive exhibition design."* Accessed April 21, 2020. https://benayoun.com/moben/bio/

Mazuryk, Tomasz, and Michael Gervautz. "Virtual reality-history, applications, technology and future." (1996).

McLellan, Hilary. "Virtual realities." *Handbook of research for educational communications and technology* (1996): 457-487.

McRobert, Laurie. *Char Davies' immersive virtual art* *and the essence of spatiality.* University of Toronto Press, 2007.

Milgram, Paul, and Fumio Kishino. "A taxonomy of mixed reality visual displays." *IEICE TRANSACTIONS on Information and Systems* 77.12 (1994): 1321-1329.
Mitchell, William John. *City of bits: space, place, and the infobahn.* MIT press, 1996.

Mokre, M. "New technologies and established institutions." *How Museum Present Themselves in the World Wide Web, Technisches Museum Wien, Austria* (1998).

Nechvatal, Joseph. "Immersive ideals/critical distances." *LAP Lambert Academic Publishing* 14 (2009): 2009.

Neumann, Ulrich, and Youngkwan Cho. "A self-tracking augmented reality system." *Proceedings of the ACM Symposium on Virtual Reality Software and Technology.* 1996.

O'doherty, Brian. *Inside the white cube: the ideology of the gallery space*. Univ of California Press, 1999.

Ooi, CanSeng. "Dialogic Heritage: Time, Space and Visions ofthe National Museum of Singapore." *Interconnected worlds: tourism in Southeast Asia* (2001).

Psarra, Sophia. "Spatial culture, way-finding and the educational message." *The Impact of Layout on the Spatial, Social and Educational Experiences of Visitors to Museums and Galleries In: McLeod, S ed. Reshaping Museum Space: Architecture, Design, Exhibitions. London and New York: Routledge* (2005): 78-94.

Pine, B. Joseph, and James H. Gilmore. *The*

experience economy. Harvard Business Press, 2011.
Psarra, Sophia. "Spatial culture, way-finding and the educational message." *The Impact of Layout on the Spatial, Social and Educational Experiences of Visitors to Museums and Galleries In: McLeod, S ed. Reshaping Museum Space: Architecture, Design, Exhibitions. London and New York: Routledge* (2005): 78-94.

Please Touch the Art, Accessed August 25, 2020, https://www.localprojects.com/work/interactive-installations/please-touch-the-art/

Pollalis, Christina, et al. "ARtLens: enhancing museum visitors' engagement with african art." *Proceedings of the 2018 ACM Conference Companion Publication on Designing Interactive Systems*. 2018.

Ratti, Carlo, and Matthew Claudel. *The city of tomorrow: Sensors, networks, hackers, and the future of urban life.* Yale University Press, 2016.

Roussou, Maria. "Immersive interactive virtual reality and informal education." *Proceedings of User Interfaces for All: Interactive Learning Environments for Children.* 2000.

Schraffenberger, Hanna, and Edwin Van Der Heide. "Interaction models for audience-artwork interaction: current state and future directions." *International Conference on Arts and Technology.* Springer, Berlin, Heidelberg, 2011.

Schueffel, Patrick. "The concise Fintech compendium." Fribourg, Switzerland (2017).

Simon, N. The participatory museum. Santa Cruz, CA: Museum 2.0, 2010. This work is available for free online at http://www. participatorymuseum. org/read/. (accessed 2/22/16).

Solko, David. *Evaluating Enhanced Reality Interfaces and the Museum Experience.* Diss. University of Cincinnati, 2018.

Styliani, Sylaiou, et al. "Virtual museums, a survey and some issues for consideration." *Journal of cultural Heritage* 10.4 (2009): 520-528.

Sutherland, Ivan E. "The ultimate display." *Multimedia: From Wagner to virtual reality 1* (1965).

Swapna Krishna, "An AR app returns stolen Gardner paintingsto their frames" Accessed June 19, 2020, https://www.engadget.com/2018-03-26-gardner-heist-stolen-paintings-arkit.html

Tanskanen, Aapo, et al. "Artificial intelligence, augmented reality and mixed reality in cultural venues." *Consolidated Assignments from Spring 2019* (2019): 80.

Tatarkiewicz, Władysław. *A history of six ideas: An essay in aesthetics*. Vol. 5. Springer Science & Business Media, 2012.64.

Technology That Serves to Enhance, Not Distract, New York Times. Accessed August 25, 2020, https://www.nytimes.com/2013/03/21/arts/artsspecial/at-cleveland-museum-of-art-the-ipad-enhances.

Thrift, Nigel. "Intensities of feeling: Towards a spatial politics of affect." *Geografiska Annaler: Series B, Human Geography 86.1* (2004): 57-78.

Tresch, John. "Technological world-pictures: cosmic things and cosmograms." *Isis 98.1* (2007): 84-99.

Vallino, James R., and Christopher M. Brown. *Interactive augmented reality.* Diss. University of

Rochester. Dept. of Computer Science, 1998.

Vanoni, David, Maurizio Seracini, and Falko Kuester. "ARtifact: Tablet-based augmented reality for interactive analysis of cultural artifacts." *2012 IEEE International Symposium on Multimedia. IEEE,* 2012.

Weil, Stephen E. "Transformed from a cemetery of bric-a-brac." *Perspectives on outcome based evaluation for libraries and museums* (2000): 4-15.

Wiesing, Lambert. *Artificial Presence: Philosophical Studies in Image Theory.* Stanford University Press, 2009.

Wojciechowski, Rafal, et al. "Building virtual and augmented reality museum exhibitions." *Proceedings of the ninth international conference on 3D Web technology.* 2004.

Worden, Suzette. "Thinking critically about virtual museums." *Proceedings of the Conference Museums and the Web.* 1997.

Yaneva, Albena. *Made by the Office for Metropolitan Architecture:* an ethnography of design. 010 Publishers, 2009.

Zukin, Sharon. *Naked city: The death and life of authentic urban places.* Oxford University Press, 2009.