Constructing Virtual Reality Exhibitions with Multimodal Interactions

by

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ABSTRACT

Even though the concept of virtual museums is still young compared with "brick and mortar" museums, it has received increasing attention in the past decades. With the rapid development of the internet and ubiquitous digital devices, human activities and focuses have shifted dramatically from physical spaces to the virtual realm, and museums must reconsider its paradigm to remain relevant in this new environment.

This thesis studies the concept of virtual museums and how it could be constructed with virtual reality (VR) as the medium. It consists of four parts in terms of methodology: a background study on the evolution of museums and the development of virtual museums; a field survey on the status quo of virtual museums and an observation of existing design methodologies; two case studies, in which two virtual exhibitions in VR are developed and evaluated; and a design guideline and three design templates generated from previous studies, to which museums can refer when designing such exhibitions in VR.

The thesis reveals that museums, as cultural institutes, have been changing their identity and shifting their focus throughout the past centuries. As the tension between their new goal to serve the general public and their long-term mission of safeguarding its collection increases, VR has proven to be a good medium for museums to extend the experience and service that museums provide. Compared with traditional physical exhibitions, virtual exhibitions in VR have advantages in terms of their capacity, connectivity, and ability to showcase spatial contexts in an immersive manner with time factors and multimodal interactions. Moreover, they could provide customized or user-generated contents in addition to convenient methods for quantitative user evaluations. A modularized design system and an object-oriented approach could help modern museums to construct exhibitions with capacity, connectivity, immersiveness, and flexibility in an efficient manner.

Thesis Advisor: Takehiko Nagakura
Professor of Design and Computation

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1 INTRODUCTION

1.1 Background

As early as 1998, Andrews and Schweibenz defined "virtual museum" as "a logically related collection of digital objects composed in a variety of media which, because of its capacity to provide connectedness and various points of access, lends itself to transcending traditional methods of communicating and interacting with visitors …; it has no real place or space, its objects and the related information can be disseminated all over the world [1]."

Even though the concept of virtual museums is still young compared with "brick and mortar" museums [2], it has been extensively studied by scholars from different fields, while the targeted medium changes from CD-ROM, the World Wide Web, and mobile applications to virtual reality and augmented reality. In an era when techniques such as cloud storage and equipment such as VR headsets have become increasingly affordable and accessible, creating virtual exhibitions in VR has become more feasible for museums. In addition, as a growing number of museums has already constructed a digital data set of their collections, including photos, metadata, and textured mesh models, for conservation and documentation purposes, it is critical to understand how they could fully utilize the data set to make their collection more publicly accessible.

Moreover, with the rapid development of the internet and ubiquitous computing, human activities and focuses have greatly shifted from physical spaces to the virtual realm. We have seen attempts, some of which have been highly successful, of using VR as part of the museum experience to allow the cultural heritages to remain relevant in people's daily lives [3], especially for the younger generations. Most of the experience, however, is designed to be used inside the museum as part of the physical exhibition. These VR experiences are highly customized based on its contents and typically require much time to develop. However, using VR to provide "off-site" visiting experiences is still under-explored.

This thesis aims to conduct a comprehensive background research and field survey on the topic of virtual museum and virtual exhibitions. It explores the possibility of constructing virtual museums and virtual exhibitions through a modularized design system and object-oriented design approach. A modularized design system is composed of different design components, such as UI elements and scenes, that could be freely configured, placed, and connected to form various design options. A object-oriented design approach means that the design is centered around artifacts (objects), including their metadata and their relationships, from museum collections. Each modules in the design system is generating from or corresponding to certain type of objects, collection of objects, or specific aspects of objects.

Based on the field survey and two case studies developed with the modularized object-oriented approach in mind, a design guideline with three design templates is delivered to illustrate the approach. The guideline is developed for traditional art museum curators and exhibition designers to efficiently create digital exhibitions in VR with multimodal interactions from existing data sets and evaluate their performances conveniently.

1.2 Hypothesis

This thesis hypothesizes that constructing VR-based virtual museums is an effective method to expand museums' virtual identity and shift their paradigm in response to the social and technological changes of contemporary society; and a design system that is modularized and object-oriented could help modern museums construct virtual exhibitions in VR with capacity, connectivity, immersiveness, and flexibility in an efficient manner.

1.3 Motivations

1.3.1 For Art Museums

The definition and focus of museums have changed dramatically throughout their course of development. To certain degrees, the shifting of museums' paradigm has always been associated with the development of new media. This is especially relevant in the

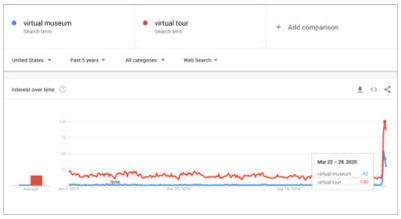
current age, in which human activities have migrated from physical environments to digital platforms. How to evolve in response to this trend of digitalization is something that museums must continue to ask themselves.

As Neil Kotler and Philp Kotler identified in 2000, museums' struggles are positioned between their mission to safeguard their collections and their goal of reaching a larger public and offering a richer visiting experience: "the risks in diluting the core activities of collections, scholarship, and education cannot be minimized. Yet, without an audience and community support, even the greatest exhibition and collection will fail to generate response [4]."

The concept of a virtual museum appears to be an adequate solution to such a dilemma. On one hand, its digital nature and association with advanced technology attracts a wider range of people, especially among the younger generation. On the other hand, it provides museums with new avenues to share their collections in addition to fresh ways of understanding the visitor experience they are providing [5]. However, one notion should be made clear: virtual museums should not replace physical museums. Instead, they should complement and fill in the gaps of physical museums [3].

Moreover, within the institutions, many museums have adopted digital systems to keep track of their collections. Since an increasing number of museums has already constructed a digital data set of their collections for conservation and documentation purposes, it appears to be a natural next step for them to consider how the data set can be shared with the public for education or research purposes. Many museums elect to either publish part of their data set directly or make it accessible through a search engine as part of their website[1]. However, how that information is presented, especially in media such as VR, in addition to their potential to create online exhibitions, is still underexplored.

1
List of museums that published a machine-readable data set: http://museum-api.pbworks.com/w/page/21933420/Museum%C2%A0APIs.



"Virtual Museum" and "Virtual Tour" Google Trends over the past five years. It is clear that there has been a sudden increase around March 2020, when the US began to adopt a quarantine and shut-down of non-essential business. Accessed 30 March. (Source: https://trends.google.com/trends/?geo=US)

1.3.2 Relevance to the Current Situation (COVID-19)

During my work on this thesis in the spring of 2020, the spreading of COVID-19 has impacted our daily lives to an extent that no one had imagined. Most states in the United States have asked for non-essential businesses to be closed and citizens to remain at home since late March. Universities across the US, including MIT, cancelled events, suspended research, and shifted all their teaching

activities to online.

Most museums needed to close their physical buildings in response to the emergent situation. At this time, the content of this thesis is especially relevant. It is important to consider the question of how museums could continue to function and serve the public during the lockdowns. In addition, it can be wondered how museums could become more resilient to similar situations in the future. The concept of virtual museums could certainly become part of the answer, which is reflected in its increasing exposure and related discussion on the internet.

1.3.3 Benefits of Creating Virtual Exhibitions in VR

Exhibitions are considered less efficient means of gathering information than books, magazines, newspapers, and the internet because of their limited texts, selective objects, and compressed narratives [4]. These limitations, however, could be greatly eliminated as exhibitions are moved into immersive virtual spaces in VR.

Compared with traditional physical exhibition spaces, virtual exhibitions offer the following advantages:

A. Capacity:
One common problem faced by art museums during contemporary time is the continuous expansion of their collections versus the limited architectural space available to display them. According to the annual report published by the National Palace Museum in Taipei, its collection of 650,000 artifacts would take more than 30 years to be exhibited if each exposition were run for three months at a time [6]. According to MFA's Online Collection Search Engine[2], with a collection of 439,156 artifacts, only 5,355 items are currently on view at MFA, indicating that only 1.2% of the collection is exhibited at the moment. In comparison, with affordable storage and high-speed internet for upload and download, digital exhibitions have almost unlimited capacity compared with physical exhibition spaces.

B. Immersive Context:
One frequent struggles of exhibition designers is how to bring the contextual information of the displayed artifacts

2
MFA Online Collection Search Engine: https://collections.mfa.org/objects/images. Accessed on April 19, 2020.

into the museum space. Those information is important for visitors to truly understanding the artifacts, but is usually difficult to present in a convincing form due to spatial and financial constraints. Virtual exhibitions, on the other hand, could efficiently showcase contextual information of the displayed artifacts in an immersive way.

C. Time Factor:
One difficult decision that museums must make is what strategy they should use to treat their artifacts. For those that have been damaged or modified by previous treatments, it can be questioned whether they should conserve the artifacts to their current state or restore them to the original state. Virtual exhibitions could display representations of objects during different stages of the restoration or aging process, adding another dimensionality to the exhibition.

D. Multimodal Interaction:
Virtual reality allows for various multimodal interactions to be tailored for different experiences. Within the virtual exhibitions, visitors could participant in the evacuation process of archeology sites with hand gestures, talk to virtual guides with speech commands, and even mimic the creation process of artworks through motion tracking.

E. Customized Experience:
Because of their digital nature, virtual exhibitions allow for different designs to be generated for people of different interests and backgrounds, either statically or dynamically. By adopting a modular design approach and objected-oriented method, each individual components of a virtual exhibition could be configured freely to create new narratives. The ability of creating such virtual exhibitions could be opened to the public, who could utilize the design system to create user-generated contents (UGC) to express their own perspectives.

F. Connectivity and Accessibility:
Virtual exhibitions could be accessible from anywhere in the world with required devices and the internet. They could reduce the barrier of physical museums by connecting their collections through recommendations or associating algorithms.

G. Quantitative Evaluation:
Virtual reality is believed to have the power of bypassing the problem of simulation behaviors of people by immersing them inside virtual environments, which could be used to evaluate spatial designs [7]. In digital settings, user behaviors can more easily be tracked and analyzed to evaluate the success of the current exhibition design.

1.3.4 Motivations of Using VR

Even though some advantages of virtual exhibition mentioned above are not unique to VR, VR is unique in that spatiality is embedded in its interface design and overall experience. The immersion of VR better aligns with museums' missions to provide visitors with an experience rather than merely displaying information, which is what web-based virtual museums commonly lack. Its spatiality makes it easy to showcase contextual information that is difficult to represent in other formats.

While museums have attempted to adopt VR applications as part of their physical exhibitions, as with other digital technologies, these VR applications are sometimes accused of isolating visitors and distracting their attention from the real, physical objects on display [8]. This is another motivation to explore whether VR as a medium may better suit the development of virtual museums when the experience is not constricted within the physical museum buildings.

On the other hand, there is rarely any discussion about the methodology in terms of designing and developing virtual exhibitions and virtual museums. Even though successful projects do exist, each has a different design process and is highly customized. This is especially true when VR is used as a medium, which has a different set of design constraints and considerations compared with designing for a physical exhibition space. The goal of this thesis, compared with most existing research, is to fully utilize characteristics of VR to design and create meaningful and effective exhibitions. In response to the lack of resources, this thesis considers existing literature and methodologies from different disciplines, such as spatial design, interaction design, data visualization, and user experience research, and attempts to integrate them into a coherent design system.

1.4 Methodology

This thesis is primarily divided into four parts in terms of methodology. It begins with a comprehensive background study of how museums have evolved throughout the centuries and how the concept of virtual museums was invented and developed. The second part includes a field survey of the quo status of virtual museums or VR experiences being implemented within museum contexts in addition to people's perspectives and experiences with using those virtual museums or VR installations. This part focuses on categorizing and evaluating the design of those virtual museums and virtual exhibitions. The third phase of this thesis mainly consists of two case studies, during which two VR exhibitions containing different content are developed, keeping in mind the notion of utilizing some modularized system. In the end, based on two previous exercises and the field survey, a design guideline is written to record observed patterns and principles of designing an VR exhibition. Three design templates are summarized from the case studies and form part of the design guideline.

1.5 Related Works

The topic of virtual museums and virtual exhibitions in VR has been studied by researchers from multidisciplinary backgrounds.

One of the earliest examples of virtual museums is Apple Computer's "Virtual Museum," a 3-D simulation of three interconnected museum spaces in QuickTime VR software [9]. In 2004, ARCO, a web-based system that allows users to access 3-D models of collections and exhibition spaces, was presented [10]. Furthermore, developed at the Open Cultural Data Hackathon GLAMhack, VIRTUE is a web-based system that allows curators to create customized virtual reality experiences that mimic traditional physical exhibition settings [11].

Outside the academic setting, VR has been widely used by museums as part of their exhibition experience. Some successful or unique examples include the Kremer Museum launched by Kremer Collection[3] (2017), Modigliani VR: The Ochre Atelier developed by Tate[4] (2017), No Spectators: The Art of Burning Man created by the Smithsonian American Art Museum in partnership with Intel and Linden Lab[5] (2018), The Enemy by Karim Ben Khelifa displayed at MIT Museum[6] (2017), Viking VR (2018), and Open Heritage launched by Google Cultural & Arts and CYARK[7]. Another

3
The Kremer Museum: https://www.thekremercollection.com/the-kremer-museum/

4
BEHIND THE SCENES - Modigliani VR: The Ochre Atelier https://www.tate.org.uk/whats-on/tate-modern/exhibition/modigliani/modigliani-vr-ochre-atelier

5
How the Smithsonian is turning its art exhibitions into virtual reality experiences: https://www.fastcompany.com/90213035/how-the-smithsonian-is-turning-its-art-exhibitions-into-virtual-reality-experiences

6
The Enemy by Karim Ben Khelifa: https://mitmuseum.mit.edu/enemy

7
Open Heritage: https://artsandculture.google.com/project/cyark

8
VR Experience: "Yayoi Kusama: Infinity Mirrors": https://connect.unity.com/p/vr-experience-yayoi-kusama-infinity-mirrors

example worth mentioning is "Yayoi Kusama: Infinity Mirrors," a replica of the physical "Infinity Mirrors" exhibition. It is designed specifically for disabled people and allows the exhibition to be accessible to them[8] (2017). On a larger scale, Virtual Museum of Canada was established in 2010 with a data set of more than 600 virtual exhibitions[9]. In addition, Virtual Archaeological Museum in Ercolano, Italy, was conceived as early as 2003 [12].

Moreover, commercial services that help galleries, museums, and artists to transform their collections or works into a VR experience have been launched. Examples include VR-ALL-ART[10], Gigoia Studio[11], and MasterArt VR[12].

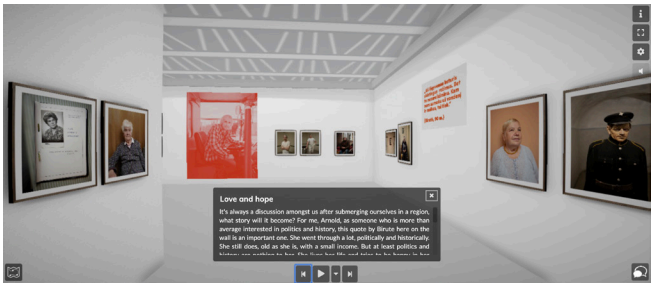
When the system is designing the environment for virtual reality, it is primarily based on the design of some existing museum exhibition spaces rather than more deeply considering exhibition design and curation. In addition, most of the research is focused on two-dimensional artworks or two-dimensional representations of artworks, while this thesis wishes to focus on three-dimensional objects.

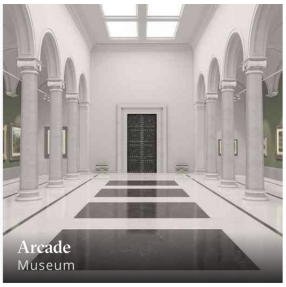
9
Virtual Museum of Canada: https://en.wikipedia.org/wiki/Virtual_Museum_of_Canada

10
VR-All_Art: https://vrallart.com/

11
Gigoia Studio: https://www.gigoiastudios.com/gallery

12
MasterArt VR: https://www.masterartvr.com/





Left
Artsteps - "The Former Capital, by The Europeans" Exhibition (Source: https://www.artsteps.com/view/5e81f24eb733f3186e8fb567)

Right
VR-All-Art (Source: https://vrallart.com/)

1.6 Intended Contribution

This thesis is meant to contribute to the field of digital humanities, especially on the subject of museum 4.0. It is intended to be viewed by museums as a reference for when they are considering ways to face the challenge of digitalization and expansion of their virtual identity. I hope this will provide museums some tools and means to expand their virtual existence and shift their paradigm. Furthermore, I hope this thesis causes readers to reflect on how museums are being perceived today and understand that their meaning and service exist far beyond their physical buildings.

2 BACKGROUND

2.1 Evolvement of Museum Architecture in the Western World

When considering the timeline of museums in the Western world, which spans more than 2,000 years, one could find that the definition and identity of museums have shifted radically. There are the repetitive shifts of a museum's role as a public institute and private sector in addition to its longtime evolution, from emphasizing the collection itself to focusing on the buildings that hold the collection and eventually provide other services to the public. The role of the museum architecture also shifted from being a container and backdrop of the collection to the "object" on display, itself.

The word "museum" is derived from the Greek word "mouseion," which means the "seat of Muses" [13]. In written records, the Museum (Mouseion) of Alexandria is the first building in the world that is named a "museum." Founded by Ptolemy I Soter in the third century BC, the Museum of Alexandria functions more like a university or philosophical academy, without any hint of art or material collections existing [14].

During the antique period, public spaces for displaying collections of significance existed often in open-air form. In addition, there are small-scale buildings in the form of temples built in the great sanctuaries, designated to receive donations. Such functionalities are adopted by public spaces, such as foras, gardens, temples, theaters, and baths, and the objects on display, including paintings and sculptures, are typically spoils of war [14].

The prototype for such a collection, called the "cabinet of curiosity", was eventually formed in Italy by the end of the 16th century. Generally a small room without windows and with a collection enclosed in wall cabinets, the "cabinets" are created as "a model of 'universal nature made private'" [14]. At the same time, a total typology, exemplified by the Kunstkammer of Albrecht V of Habsburg, is developed, as well. Occupying the wings of a

quadrangle, such a structure eventually evolved into the prototype of art museums [14].

The end of the 17th century to the 18th century marks the shift of such collections to become public again. Associated with the spirit of Enlightenment, such displays were moved from private sectors into public buildings, including universities, churches, and monasteries. Until the end of the 18th century, the word "museum" still referred to a collection of valuable objects rather than a building containing the collection. It was also during the 18th century that people began to view museum buildings as an object of study and conscious design [14]. At this time, an ideal museum layout typically consisted of a series of inter-connected rooms, each housing a different self of collections. The rooms were arranged in a linear format, departing from the entrance and returning to the same place. Such a layout generally provides a predefined path of visiting, without leaving much choice to the visitors. As some were adapted from display spaces in royal palaces, the museum buildings sometimes shared characteristics of palace architecture. In addition, generally considered the "temple of art," museum buildings always borrowed elements from Greek temples, including the pedimented portico with columns, symmetrical layouts, and rotandos in the central space sometimes created with a grand staircase [14]. Such elements can still be seen in museum buildings constructed relatively recently, including the Museum of Fine Arts in Boston.

The First Industrial Revolution began in the 18th century and introduced new building materials, such as steel and glass, which greatly influenced architectural designs, including those of museums. In the second half of the 19th century, initiated by the International Exhibitions and EXPO structures such as the Crystal Palace, two significant features were incorporated in museum architecture: "impermanence and flexibility" [15]. Rather than a series of rooms, the spatial layout of museum buildings became free plans organized by removable panels [14].

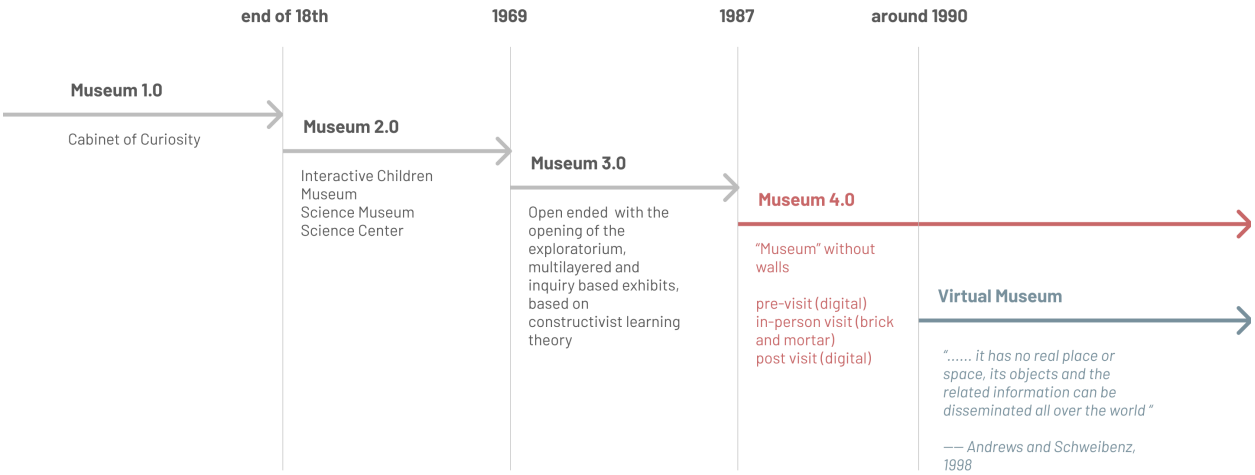
A series of anti-typology exploration emerged in the 20th century, including the system of parallel galleries connected to the central nucleus of the Musee Moderne of Auguste Perret in addition to the continuous spiral layout created by Le Corbusier for the Musee Mondial. Another landmark design is demonstrated by the Museum of Modern Art in New York City (MoMA), which introduced the white flexible display space into the viewpoint of mainstream museum space design [14]. In addition, it is the first architecture

to organize its exhibition spaces vertically rather than horizontally and to have a directly accessible entrance facing the street as a replacement to the monumental staircase. Two decades later, Solomon R. Guggenheim Museum in New York City, featuring a spiral ramp that dominates the central space, appeared as a modern monument in the city. It served as the milestone of architecture beginning to shift to the center stage as an artistic expression rather than a functional container [14].

Later in the 20th and 21st centuries, it became common for museum architecture to be designed as a unique object, typically in its physical forms. In addition, compared with the predefined visiting path that was common in classical museum building typology, modern designs, such as the 21st Century Museum of Contemporary Art in Kanazawa, Japan, began to implement the idea of actively discouraging predetermined paths.

To summarize, the shifting trends in the design of museum architecture reflects the shifting perception and paradigm of museums as an institution, which are relevant as we imagine the future of museums.

2.2 Museum 4.0



In alignment with the evolution of museum space, Mark Walhimer identifies the four development stages of a museum: museum 1.0 as the cabinet of curiosities format; museum 2.0 as museums such as science centers that incorporate interactive technologies

into their exhibitions; museum 3.0 as "open-ended constructivist" with exploratorium, multilayered, and inquiry-based exhibitions; and museum 4.0 as a "museum with walls." For museum 4.0, the museum experience is divided into three parts: pre-visit, in-person visit, and post-visit, each of which could be fulfilled by physical spaces, digital contents, or both [16]. In addition to the adoption of various technologies, such as radio frequency identification RFID, social media, and Bluetooth mesh technologies, museum 4.0 should be able to provide a personalized experience depending on the visitor's age group, background, and interests [16].

From museum 1.0 to museum 4.0, we can see that the focus of museums has been shifted from their collection of objects to a public space that promotes conversation and learning. Modern museums focus more on providing an experience to its visitors, which is not only limited to the time that people spend in the museum building but also their experience prior to and after the visit.

2.3 Concept of Virtual Museums

"..... a logically related collection of digital objects composed in a variety of media which, because of its capacity to provide connectedness and various points of access, lends itself to transcending traditional methods of communicating and interacting with visitors ……; it has no real place or space, its objects and the related information can be disseminated all over the world"

---- Andrews and Schweibenz, 1998

Even though the concept of the virtual museum is still young compared with the "brick and mortar" museum, it has evolved for nearly three decades now. During its initial stage, virtual museums could be categorized into two groups: one that considers using digital media as a way to communicate, which is prior to physical exhibitions and paper publications, and one that emphasizes the creation of an immersive space for display, which is tightly connected with the concept of VR [17].

Undoubtedly, similar to "museum," the term "virtual museum" generally is loosely defined, accompanied by many digital applications and contents claiming to be one of it. Based on the definition provided by the International Council of Museums (ICOM), "A museum is a non-profit, permanent institution in the service of society and its development, open to the public, which acquires, conserves, researches, communicates and exhibits the

tangible and intangible heritage of humanity and its environment for the purposes of education, study and enjoyment[13]." Based on this definition, when a virtual museum is defined as "a digital entity that draws on the characteristics of a museum, in order to complement, enhance, or augment the museum experience through personalization, interactivity and richness of content[14]," its primary goal should still be to provide education, study, and enjoyment to the public that is centered around the heritage of humanity.

In 1991, Jeffery Shaw published a multi-media installation titled "Virtual Museum." The installation is composed of a round, motorized rotating platform, a chair that allows the user to sit and control the experience, and a large video projection monitor with a computer. The "museum" is a three-dimensional computer-generated virtual space with exhibitions inside. Visitors can navigate inside the virtual space by moving the chair forward and backward and change their view by rotating the chair with the round platform[15]. In 1992, Apple Computer published a CD-ROM of the same title: "Virtual Museum." Known as the first digital virtual museum, it contains 3-D simulations of three interconnected museum spaces displayable in QuickTime VR [18]. On the CD-ROM package, the content is described as "an interactive, electronic museum where users can move from room to room, and select any exhibit for more detailed examination." The exhibitions cover a wide range of topics, including medicine, plant growth, the environment, and astronomy [17]. In 1999, the Guggenheim Virtual Museum was commissioned by the Solomon R. Guggenheim Foundation and designed by Asymptote Architecture. Designed as a dynamic 3-D virtual space inspired by the spiral form of the Guggenheim Museum in New York City, it "marked the first substantive commitment to interactive, computer-based works of art by a major U.S. museum" and was conceived as an experiment for exploring the future of museums.

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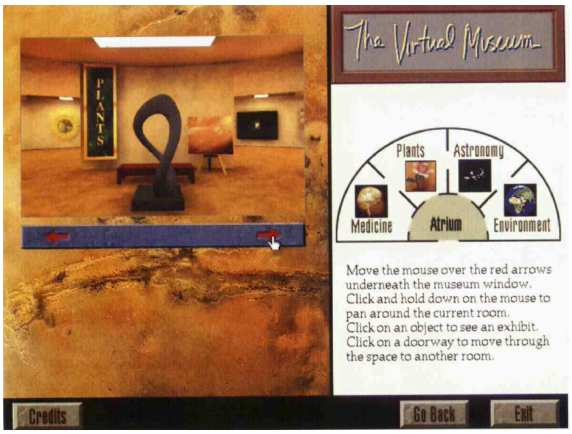
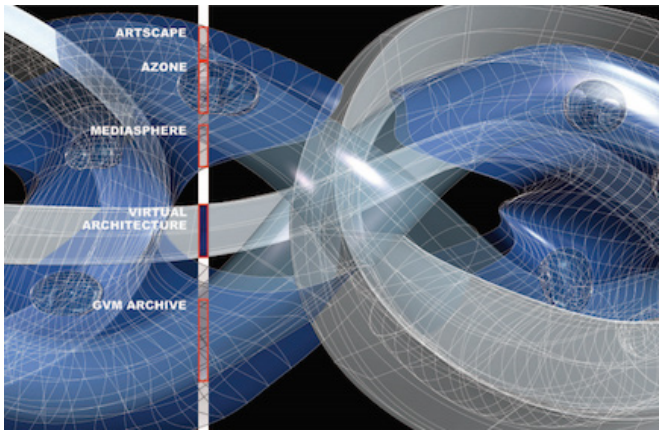
13
ICOM Definition of a Museum. http://archives.icom.museum/definition.html

14
Virtual museum. 2020. Wikipedia. https://en.wikipedia.org/wiki/Virtual_museum.

15
The Bohen Foundation. http://bohen.org/project/virtual-museum.

displayable in QuickTime VR [18]. On the CD-ROM package, the content is described as "an interactive, electronic museum where users can move from room to room, and select any exhibit for more detailed examination." The exhibitions cover a wide range of topics, including medicine, plant growth, the environment, and astronomy [17]. In 1999, the Guggenheim Virtual Museum was commissioned by the Solomon R. Guggenheim Foundation and designed by Asymptote Architecture. Designed as a dynamic 3-D virtual space inspired by the spiral form of the Guggenheim Museum in New York City, it "marked the first substantive commitment to interactive, computer-based works of art by a major U.S. museum" and was conceived as an experiment for exploring the future of museums[15].





Left - The Virtual Museum by Apple Computer Inc,. (Source: Miller et al. 1992)

Right - Guggenheim Virtual Museum. (Source: http://bohen.org/project/virtual-museum. Asymptote Architecture: Hani Rashid and Lise Anne Couture)

While the examples above attempt to create virtual but immersive 3-D exhibition spaces, some examples focus on the digital content itself rather than the virtual exhibition space. One pioneer is the WebExhibits project. Developed by Michael Douma at IDEA in 1999, the first version of WebExhibits includes directories of cultural and scientific offerings at other sites. It "uses information, virtual experiments, and hands-on activities that prompt visitors to think, to formulate questions, and to explore topics from a variety of angles[16]." Upon viewing it today, one may argue that WebExhibits does not qualify as much as a virtual museum, because while it communicates curated information, it does not exhibit any artifacts [17].

16
WebExhibits. 2019. Wikipedia. https://en.wikipedia.org/wiki/WebExhibits.

Based on its definition, a virtual museum is not limited to only contents that could be explored outside the museum but also those designed as part of a physical exhibition inside the museum

WebExhibits. Accessed April 20th, 2020 (Source: http://www.webexhibits.org/)

to augment or enhance the experience. One example is Kivotos, a virtual reality environment based on a CAVE system that visitors can experience with stereoscopic 3-D glasses and magic wands [19]. The Herbert Virtual Museum is a mobile application developed by the Serious Games Institute and Coventry University in collaboration with the Herbert Art Gallery. While providing a virtual gallery space for visitors to navigate in addition to other multimedia information for artifacts located inside the gallery, the application is also characterized by its content management system, which allows the museum to dynamically update the content of the virtual museum [19].

Furthermore, as a growing number of museums has already constructed a digital data set of their collections, including photographs, metadata, and textured mesh models for conservation and documentation purposes, some projects are considering a more systematic way of utilizing those data sets and building virtual museums based on that. In 2000, 3D MURALE was created as a system for recording, reconstructing, encoding, and visualizing artifacts found in archeology sites [20]. Developed in 2004, ARCO is a comprehensive architecture of digitalizing and managing the artifacts, in addition to presenting the objects in web-based virtual galleries with 3D VRML [21]. Published in 2019, the VIRTUE system is a generic, customizable virtual reality system in which curators can easily create multi-modal, virtual 3-D exhibitions [22].

3 FIELD SURVEY

3.1 Current State and Categories Virtual Museums

Today, most museums have already begun to consider ways of extending the experience they provide into the virtual realm. Museums are collaborating with research groups and organizations such as Google Art and Cultural to digitize their collections, exhibitions, or both and present them through the internet. As part of the field survey, I began compiling this data set of virtual museums and exhibitions, within their broadest definitions, and identified some major types of virtual museums.

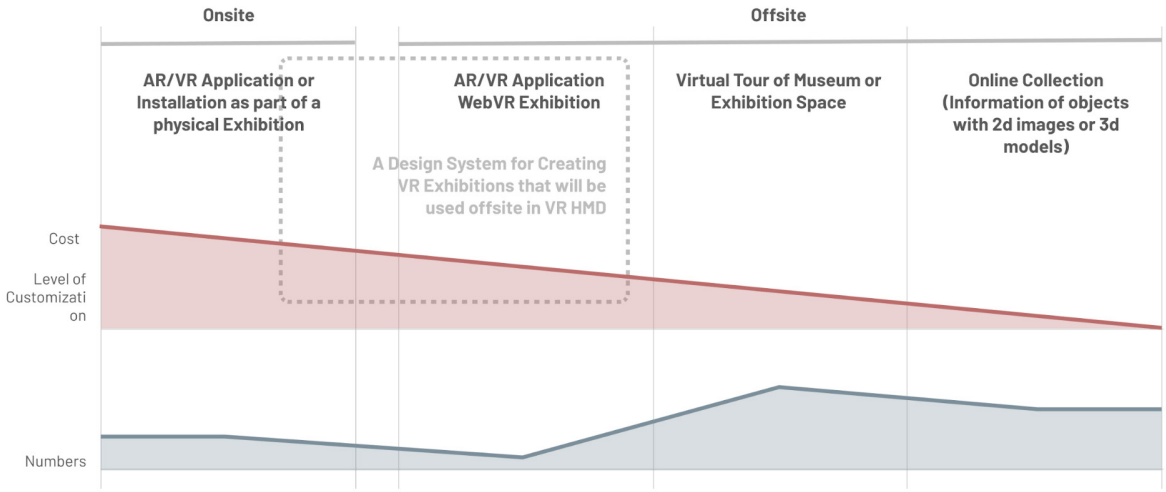
Name	Link	Label	Year of Creation	Language	Collection Type	Creator	Number of Items	Has Physcial Counterpart	Technology	Media	Musem Type	Comments	Onsite/Offsite
Vincent van Gogh Gallery	http://www.vggallery.com/index.html	OnlineCollection	1996	English	Artist	Individual	2180			Web	Art		Offsite
Rijksmuseum Masterpieces Up Close	https://www.rijksmuseum.nl/en/masterpieces-up-close	VirtualTour		English	Museum	rijksmuseum		Yes	360Image	Web	Art		Offsite
Guggenheim's Online Collection	https://www.guggenh	OnlineCollection		English	Museum	Guggenheim		Yes		Web	Art		Offsite
Zhengzhou Museum Virtual Tours	http://www.hnzzmuse	VirtualTour		Chinese	Exhibition	Zhengzhou Museum		Yes	360Image, Audio	Web	Art		Offsite
Zhengzhou Museum 3D Objects	http://www.hnzzmuse	OnlineCollection		Chinese	Museum	Zhengzhou Museum	11	Yes	ModelViewer	Web	Art		Offsite
Dongqichang Calligraphy and Drawing Art Exhibition at Shanghai Museum	https://www.shanghaimuseum.net/museum/dongqichang/index.html	OnlineExhibition		Chinese	Artist, Exhibition	Shanghai Museum		Yes	DataVisualization, WebVR	Web	Art	The online exhibition is carefully designed with not only the artworks but nice visualizations of a timeline as well as interpersonal relationships of the artist	Offsite
Meet the Tang Dynasty Again - Liaoning Museum	http://www.lnmuseum	VirtualTour		Chinese	Period, Exhibition	Liaoning Museum		Yes		Web	Art		Offsite
Online Exhibitions - Shanxi Museum	http://www.shanximu	VirtualTour		Chinese	Exhibition	Shanxi Museum		Yes	360Image, InteractiveMap, Audio, InteractiveAnnotation	Web	Art	This site contains a series of virtual tours of Shanxi Museum's current exhibitions. Besides the panorama images that capture the phyiscal environment of the exhibitions, the virtual tours also contains interactive components such as interactive maps, annotations, and audio.	Offsite
Suzhou Museum	http://www.szmuseum.c	VirtualTour		Chinese	Museum	Suzhou Museum		Yes	360Image, InteractiveMap	Web	Art	The virtual tour of Suzhou museum includes a series of panorama images that linked together like Google Map Streetview, to showcase the architecture designed by I.M.Pei. It also includes interactive maps for users to navigate around the building.	Offsite
Apple "Virtual Museum"		VirtualMuseum	1992	English	Exhibitions	Apple Computer		No		CD-ROM	Science	Virtual Museum is CD-ROM published by Apple Computer in 1992. It is a 3-D simulation of three interconnected museum spaces in QuickTime VR software. On the package, it has been described as "an interactive, electronic museum where users can move from room to room, and select any exhibit for more detailed examination. The exhibits cover such topics as medicine, plant growth, the environment and astronomy."	Offsite
												The Virtual Museum is a multi-media installation designed by Jeffery Shaw in	

Screenshot of part of the database of different types of virtual museums and virtual exhibitions

In addition to VR/AR applications that are often installed as part of a physical exhibition, virtual museums that can be accessed offsite could be divided into three major categories: AR/VR application or WebVR contents, virtual tours, and online collections published by

museums. From left to right among the three categories, the cost of constructing such an exhibition decreases as does its level of customization.

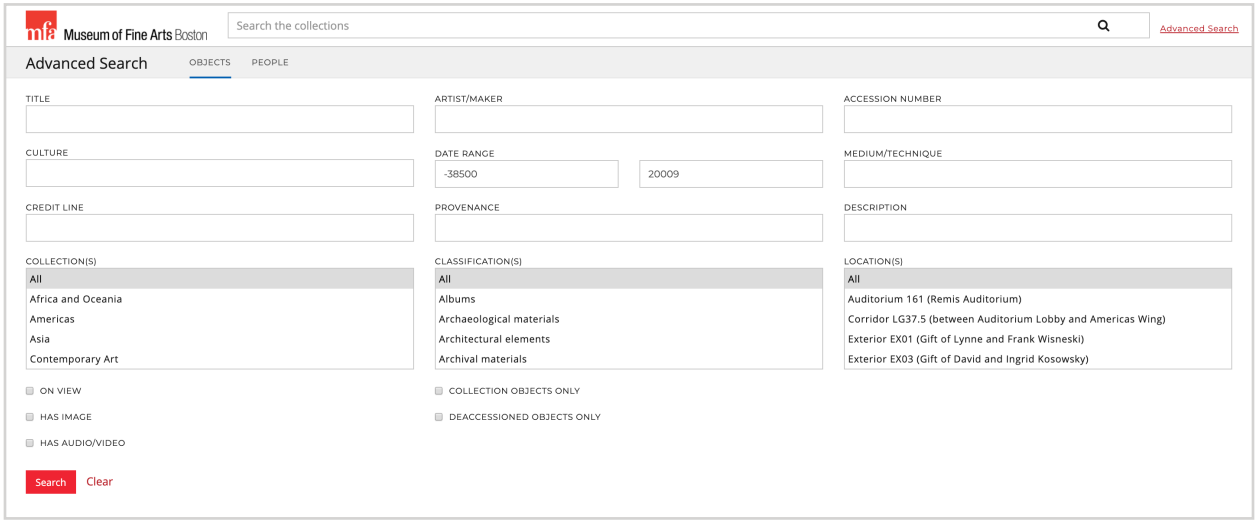
Different categories of virtual museums and virtual exhibitions



3.1.1 Online Collections

Online collections are typically presented as a major part of museums' websites. Most of the time, they allow users to access the artworks in which they are interested by searching or browsing. Most online collections have more advanced features, such as sorting and filtering, allowing users to explore specific groups of artifacts based on cultural context, collection, date of creation, and so on. Since giving the public access to such online collections is gradually

MFA Collection Search Webpage. Accessed April 20th, 2020 (Source: https://collections.mfa.org/advancedsearch)



becoming common practice among museums, an increasing number of discussions is being held regarding such a system, from both design [23] and management perspectives [24].

Artwork	Title	Artist/Culture	Date	Medium	Gallery	Accession #
	**Armor (*Gusoku*)**	**Helmet signed by Bamen Tomotsugu** Japanese, Eichizan province, Toyohara, active 18th century	18th century	Iron, lacquer, copper-gold alloy (shakudō), silver, silk, horse hair, ivory	On view at The Met Fifth Avenue in Gallery 377	2001.642

A sample result from the Metropolitan Museum of Art (MET) Collection Search Webpage. Accessed April 20th, 2020 (Source: https://www.metmuseum.org/art/collection/search#!?q=japan&perPage=20&searchField=All&sortBy=Relevance&offset=0&pageSize=0)

Some museums also provide a downloadable data set or API to provide researchers access to the raw data for their collection website. These data sets are proven to be extremely valuable for researchers of different backgrounds and have inspired a variety of interesting projects within the fields of data visualization, machine learning, and computer vision, among others[17].

Information contained in those data sets are usually texts that describe the title, theme, medium, and artist of each artwork and are sometimes accompanied by various images of the artworks. However, attempts have been made to share other types of content, including audio, video, and textured 3-D models. Despite the rich types of information, the designs and layouts of those webpages are typically quite genetic, simply duplicating "familiar museum products and information [24]," which has changed little over the past 15 years [23].

Similar to the WebExhibits project, it is questionable whether such collections count as virtual museums; however, their existence does promote the development of more advanced projects. One example is the Google Art and Cultural "Explore connection" section, which constructs a much broader network of artwork by connecting objects from different museums' collections. Another related project is "Slice of MoMA," which is developed by Qianhui Liang, Jialu Tan, and me as part of the interactive data visualization class. Based on the collection data set published by the Museum of Modern Art (MoMA)[18] and focusing on extracting colors and visual similarities from the artworks with the OpenCV[19] and VGG16[20] models, our project allows users to explore MoMA's collection in a more inspirational way. "The Museum of the World"[21] is presented by the British Museum in collaboration with the Google Cultural Institute. Described as an "interactive experience through time,

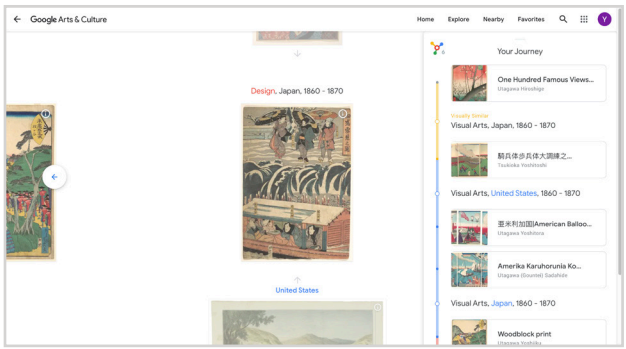
17
Harvard Art Museum - Access to the API: https://www.harvardartmuseums.org/collections/api

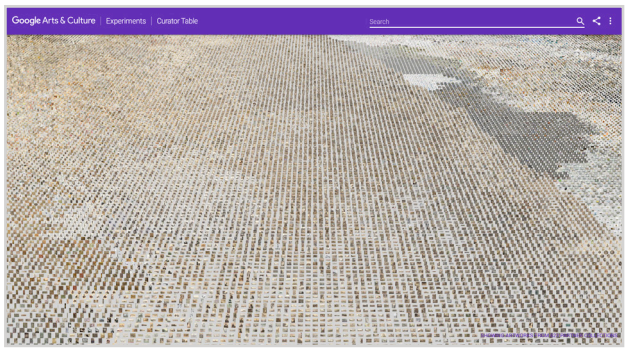
18
The Museum of Modern Art (MoMA) collection data: https://github.com/MuseumofModernArt/collection

19
Open Source Computer Vision Library: https://github.com/opencv/opencv

20
Keras Documentation - Available Models - VGG16: https://keras.io/applications/#vgg16

21
The Museum of the World. Google. https://britishmuseum.withgoogle.com/about.

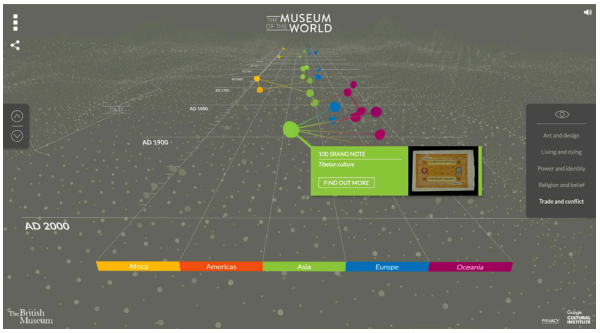


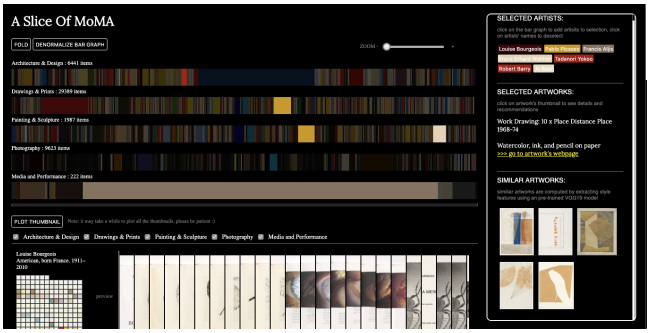


continents, and cultures," it presents the British Museum's collection on a timeline and associates the artwork by hidden links. A similar example is "Curator Table," developed by Cyril Diagne and Simon Doury in 2017[22]. Based on the examples mentioned above, one can see a strong trend in combining the concept of a virtual museum with interactive data visualization. In those cases, the virtual spaces that contain the collection become more conceptual and begin to deviate from the design of traditional physical exhibition spaces.

Left: Google Art and Cultural. Explore Connection. Accessed April 29, 2020 (Source:https://artsandculture.google.com/journey/create/cwEPQk4UO2sF-Q)

Right: Curator Table. Accessed April 29, 2020 (Source:https://experiments.withgoogle.com/curator-table)





Left: The Museum of the World. Accessed April 20, 2020 (Source: https://britishmuseum.withgoogle.com)

Right: A Slice of MoMA. Accessed April 20, 2020 (Source: https://lqh-0514.github.io/modern-art-museums/)

3.1.2 Virtual Tours

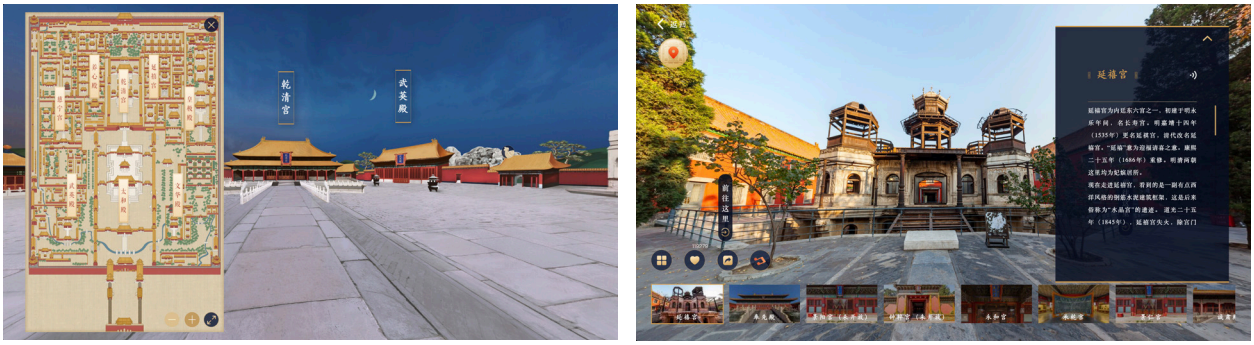
Virtual tours are another major component of the virtual museums of today. Virtual tours are always in the same format of Google Street View, which is a series of panoramic images taken inside the physical exhibition space. Interconnected with one another, they allow users to navigate through the space by clicking through each frame of the images. This approach is used not only by museums but also cultural heritage sites. More advanced features common in virtual tours are annotations attached to certain locations on the panoramic images in addition to interactive maps displaying the floorplan of the museum building with locations of the panoramic

22
Curator Table: https://experiments.withgoogle.com/curator-table

images.

One successful example is the "Panoramic Palace Museum" project created by the National Palace Museum in Beijing, China[23]. Compared with other projects that adopt similar approaches, the "Panoramic Palace Museum" has a much more sophisticated visual design language and user experience, which incorporates digital models, drawings, images, and audio. In addition, it has seasonal events to keep the virtual experience up to date.

23
Panoramic Palace Museum: https://pano.dpm.org.cn/gugong_app_pc/index.html



Panoramic Palace Museum. Accessed April 20, 2020. (Source: https://pano.dpm.org.cn/gugong_app_pc/index.html)

Even though they are developed in a common format to showcase exhibition spaces, virtual tours have many limitations. For instance, depending on the number of panoramic images that can be taken, virtual tours can allow the users to view the exhibition space from only a restricted set of locations and angles, so many contents of the exhibition, such as text panels and labels, are not readable. Moreover, even though they are not necessary in such a case, visual barriers, such as glass, still exist in those panoramic images. To conclude, this approach might better suit documenting and presenting cultural heritage sites and architecture spaces rather than the smaller-scale objects that more commonly appear in art museums.

3.2 Examples of VR Technology Applied to Museum Experience

3.2.1 Onsite Experience

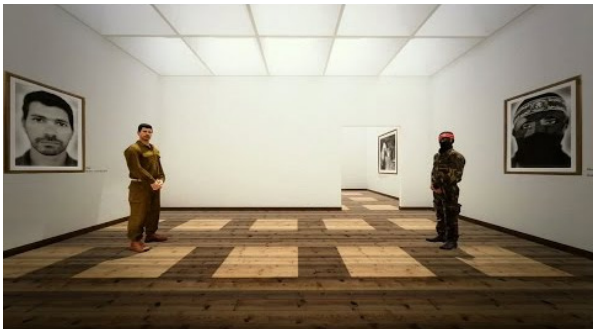
As equipment such as VR headsets and tracking sensors has become more affordable and accessible, museums are also considering ways to integrate this new technology into their exhibition experience. Compared with online collections and virtual tours, most of those VR experiences could be deeply integrated into the physical exhibition space of the museum and are meant to be experienced by

visitors as part of their in-person visiting experience.

Modigliani VR: The Ochre Atelier. Courtesy of Preloaded. (Source: https://www.tate.org.uk/whats-on/tate-modern/exhibition/modigliani/modigliani-vr-ochre-atelier)

Modigliani VR is a project developed by TATE Modern in London as part of its exhibition of Modigliani's artwork[23]. It recreates the working environment of the artist with carefully constructed models and animations. By inviting the visitors inside, it showcases the behind-the-scenes aspect of Modigliani's artworks, which is commonly missing in most exhibitions. A similar example can be seen with A Journey Inside Paintings and Calligraphy - VR ART exhibition curated by the National Palace Museum at Taipei[24], which consists of three parts: "Up the River During Qingming VR," "Roaming through Fantasy Land," and "The Spirit of Autobiography." Among these, "Up the River During Qingming VR" is based on the masterpiece painting "Up the River During Qingming." The VR experience showcases the detail of the scroll by turning its iconic scenes into interactive game environments. By recreating the famous painting as a virtual 3-D space, it invites the visitors to step into the painting, granting them a deeper understanding of the content of

23
BEHIND THE SCENES - Modigliani VR: The Ochre Atelier https://www.tate.org.uk/whats-on/tate-modern/exhibition/modigliani/modigliani-vr-ochre-atelier



The Enemy by Karim Ben Khelifa (Source: https://mitmuseum.mit.edu/enemy)

the painting.

Another highly successful example is the Enemy, exhibited at the MIT Museum in 2017[25], which tells a controversial story from

multiple perspectives. What is unique about the Enemy is that the exhibition is not associated with any physical artifacts but rather is centered around its narrative. During the exhibition, visitors are equipped with a headset and a backpack containing the battery.

A Journey Inside Paintings and Calligraphy – VR ART (Source: https://theme.npm.edu.tw/exh107/VRart/en/page-1.html)

3.2.1 Offsite Experience

On the other hand, those VR applications are not limited to be used within museum spaces. One example is the application "Dreams of Dali" developed by the Dali Museum, which transforms Dali's painting Archaeological Reminiscence of Millet's "Angelus" into a 3-D landscape with sound effects and animations[26]. In addition to being presented inside the museum, the application is also released across different platforms and can be viewed by anyone at home with an Oculus or HTC Vive headset.

In some cases, VR exhibitions could also be constructed for special purposes. One example is a virtual museum designed for artwork that has been stolen from museums and galleries. Another example is a virtual version of the famous Infinity Room exhibition; the museum created the VR version specifically for disabled people with wheelchairs, since they cannot access the real museum.

Moreover, other applications have been developed by different organizations or individuals to provide a similar experience. Even though they typically lack the authority of museums, suggesting that the quality of the content is not guaranteed, the way they design the experience and present the artwork could be inspiring. For example, the "Rougeau Gallery" is a personal gallery space with a garden released on the Oculus App Store. It features 150 works by contemporary artist Kenneth Rougeau and incorporates

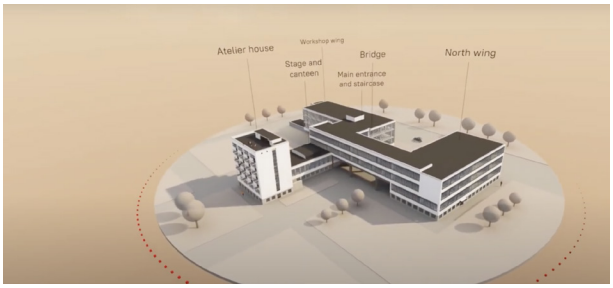
24
A Journey Inside Paintings and Calligraphy. A Journey Inside Paintings and Calligraphy – VR ART. https://theme.npm.edu.tw/exh107/VRart/en/page-1.html.

25
The Enemy by Karim Ben Khelifa: https://mitmuseum.mit.edu/enemy

26
Dreams of Dalí in Virtual Reality. Salvador Dalí Museum. https://thedali.org/exhibit/dreams-of-dali-in-virtual-reality/

interesting themes, such as Alice In Wonderland, into the design[27]. Another example is the "Virtual Bauhaus" developed by the Goethe-Institut on the occasion of the Bauhaus centennial. It created the architectural space of the iconic Bauhaus Dessau building designed by Walter Gropius, which is accomplished by providing multimedia contents located inside the virtual space to complete the narrative of Bauhaus's history[28].

27
The Rougeau Gallery on Oculus Rift. Oculus. https://www.oculus.com/experiences/rift/1678008145654823/?locale=en_US.



Left: Dreams of Dali. (Source: https://thedali.org/exhibit/dreams-of-dali-in-virtual-reality/)

Right: Virtual Bauhaus Tour (Source: https://www.goethe.de/ins/us/en/sta/bos/ver/vib.html)

28
Virtual Bauhaus. Goethe. https://www.goethe.de/ins/us/en/sta/bos/ver/vib.html.

Similar to online collections and virtual tours, more customized and advanced VR applications also have their own limitations. First, when such contents are used inside museum spaces as part of an exhibition, acquiring the VR equipment and maintaining it could be expansive for museums. Second, such installations are typically scattered at different spaces inside the museum building without a central management system, which means it is difficult to scale. Moreover, although immersive VR generally provides an isolated experience to individual visitors, this may result in long waiting times and minimal social interaction among the visitors. Last, when people are immersed inside the VR experience, they have minimal awareness of their surroundings, which might include valuable objects if inside a gallery space. Therefore, the VR experience may require its own empty space, which is not easy to find in current museum designs [25].

Due to the above limitations, providing VR contents to be used offsite appears to be a better practice for museums. However, to access the content, the users must possess their own VR devices, which introduces the question of digital divide. Such a solution appears to contradict the museums' institute goal of serving the public inclusively.

3.3 Interviews

As part of the research, I also interviewed individuals who work

in the field as different roles: curators, conservators, and art preparators. I interviewed them with questions regarding their daily job at museums and galleries, their general perspectives of the identity of museums at the current time, their worries and concerns about museums, and their viewpoints on the concept of virtual museums and virtual exhibitions realized through VR technology.

I would like to thank all my interviewees—Tomoko, Eve, Linsly, Abigail, Jones, and Timothy—who agreed to lend some of their precious time to me and my research. Their inputs truly provided guidance for me to specify the direction of this project and further develop it.

3.3.1 Conversation with Tomoko Nagakura—Curator at MFA

Tomoko Nagakura is a curator working in the Asian Art Department at the Museum of Fine Arts (MFA). She is the first person I spoke with when I had only an initial idea of designing a tool for museum curators to create virtual exhibitions. She introduced me to some operations within the MFA. For instance, in addition to the permanent exhibitions, most exhibitions rotate every 6 to 9 months. For the Art of Japan division, curators and exhibition designers typically display seasonal contents that are pertinent to the moment. For instance, during the spring, the team curates a collection of objects that have a spring theme, such as paintings with flowers blooming in the spring. Moreover, she confirmed some of my previous claims as we discussed the current problems of museums, including the lack of physical space to display all the artifacts in addition to the long-lasting difficulty of presenting contextual information of the displayed objects. Furthermore, we spoke about the role of museum and curator. She mentioned that the role of curator has shifted from someone who answers questions raised by the visitors to someone who asks questions to the visitors. The goal of museums and their exhibitions is to facilitate discussions surrounding certain topics rather than provide an answer.

3.3.2 Conversation with Eve, Linsly, and Abigail - Conservators at MFA

Eve, Linsly, and Abigail work in the conservation team in the Asian Art division at MFA. They introduced me to structures between different departments at MFA: conservation departments are generally divided based on the type of objects, with the exception of the Asian Art division, primarily due to its specialty in material.

They also provided me with many details of how the conservation team operates. For instance, different types of materials are typically collected for conservation purposes, as presented in the table below.

Documentation performed by other departments as well, such as the Photo and Media Service Departments	Conservation (and documentation) performed by conservators	Context
Photographic (nice image) Attempt to make the most perfect shot with the proper lighting and background; must be beautiful	Annotated Images (more details) Pre-treatment documentation—more for record, conditional issue—could be shared with the public if it is interesting It usually includes color bars to calibrate; do not need to be perfect but must convey information	Photogrammetry (for interpretation) Travel to site—place objects into photogrammetry model of contexts Lighting condition in Mid Age is different and thus influences the choice of colors/paints
Archival Images—from the past/past displays Display past conditions of objects—pieces begin missing along the way and no other documentation as to why	Ultraviolet Photography	Color Recreations Recolor photogrammetry models textures to reveal how objects really look before the paints disappear—conservators could recover color information carefully but would not be able to display this information easily
Time-Lapse Videos—for important set-ups	Infrared Reflectography (IRR) Easier to read compared with normal camera (carbon-based materials)	VR & AR & MR Such installation should have a designated room or large couch so that visitors would not need to walk around while carrying the device
Static Didactic Displays Done for various purposes, such as education	Micrographs Close-up details; how decoration is applied	Computer-Generated Imagery (CGI) While having the knowledge of how it should look, museums typically lack digital models to that level of detail.
Construction videos Such an approach typically has an easier explanation process. Replicas could be sold in traditional temples and used as a learning process for conservation students. One example is the Nara National Museum.	Reflectance Transformation Imaging (RTI) A computational photography technique. About 40 normal images are taken under different lighting conditions with static objects and cameras. This method is helpful for conservators to see the topography of the objects.	

	Photogrammetry—track topography This method is useful for detecting high-level changes or monitoring cracks on wood structures. It could also be used within applications for display purposes after reducing the size.	
	X-Ray Radiographs Conservators generally use them to view the interior structures of objects, but they may be interesting to the public	
	Computerized Topography (CT) This method is expensive, and objects must be sent to specific laboratories to be scanned. Since the machine is not designed for artifact conservation purposes, it is easier to scan something in human form, such as sculptures.	

Based on the table, one could see that the material collected by the conservation team usually covers a wide range and can provide many insights into the objects that are not presented in the objects themselves. The concept of utilizing those materials in virtual exhibitions is compelling, especially when revealing the conservation process to visitors.

From a conservation perspective, an artifact is always in a changing state, and the question of the state in which the museum should keep it is under frequent debate. The strategy changes among museums based on their focus. More specifically, for a history museum, it is likely important to show how the object should be within history; meanwhile, for an art museum, it may be more important to make the object appear visually appealing. At MFA, the strategy is to keep the object in its current condition unless factors are causing active harm. The researchers in the conservation team are also considering ways of learning about the object without harming it. Such findings, as well as the conservation process, are something the conservators hope to share with the public. Traditionally, that information is interpreted into texts and images and displayed on

panels accompanying the target objects. However, many attempts have been made for the experience to be more interactive. Currently occurring at MFA is the "Conservation in Action" project[30], which transforms an exhibition floor into a conservation space contained by glass walls so that the visitors could observe the working environment, equipment, and tools of conservators and understand how they perform their work on selected objects. Both of these contents could easily be transformed into a virtual exhibition, in which there will be fewer constraints regarding space and time.

When the discussion returned to general concerns about the current state of museums, the conservators mentioned that attendance has been lowering; therefore, attempts have been made to make the museum more adaptive, better curated to younger people, compatible with social media, and suitable for the creation of public spaces to support the exchange of ideas. Art is traditionally made and consumed by elites, who collect it to reinforce their status. However, such a statement no longer applies to the contemporary time. The classic museum buildings of today still have a formal, cold, and quiet environment, which is not welcoming, especially for kids. Additionally, while the museum wishes to attract a larger audience, it requires background knowledge of the visitors to appreciate the art, but education focuses in the US have shifted. Last, compared with other types of entertainment, museums are still quite expansive.

When discussing digital museums, the conservators expressed that from their perspective, seeing the actual object is still the most valuable part of a museum experience. Photography is mediated, as is the digital model of the objects. It is important to consider how to allocate resources between conserving and displaying the actual object as opposed to digitally archiving it. In terms of reaching a wider audience, digital museums could be a good means. Since no one can prevent the younger generation from using digital media, museums should learn to use it to their advantage.

One interesting topic raised regarding the digitalization of a museum's collection is the ethnic issue surrounding it. This concerns how to identify and prevent digital colonialism, and solving copyright issues still requires much discussion and clarification. Moreover, digitalizing something does not equate to preserving something.

3.3.3 Conversation with Caroline A Jones—Professor at MIT and former curator at MoMA

30
MFA Conservation in Action: Japanese Buddist Sculptures: https://www.mfa.org/collections/conservation/conservation-in-action/japanese-buddhist-sculptures

Caroline A Jones is a professor in the History, Theory, and Criticism section in the Department of Architecture at MIT. She worked as a curator at MoMA formally and has extensive knowledge of art curation and art history. Our discussion is centered on curation strategies and the notion of "institutional critique." which means to give people the tools to curate their own exhibition and choose their own path of navigation. One example is MoMA, in which it is used to provide a much more constrained visiting experience. For instance, guards inside the gallery space would ensure that visitors walk in only one direction; however, such an approach has been criticized by post-modern artists. In comparison, MoMA has attempted to mix up all curators, which causes people to be excited, as it is more democratic.

Caroline mentioned that exhibition curation concerns ideology and critical act, which means that when museums curate and design exhibitions, this inevitably enforces its ideology upon the visitors and tells the story from a single perspective. What would be interesting with a virtual museum is that if a sufficiently large database could be provided, people could be asked to curate their own exhibition, in which case the ideology behind the exhibition is left to the visitors. Closely related to this theme, algorithms that inspire people and help them to discover new things are also worth exploring.

3.3.4 Conservation with Timothy J Lloyd—Gallery Manager at MIT List Visual Arts Center

Timothy J Lloyd works as the gallery manager at the MIT List Visual Arts Center. Working as an art preparator for many years, he has much experience collaborating with curators and artists to prepare art exhibitions of various content. He introduced me to his process of planning and designing exhibitions for the MIT List Visual Arts Center. This process typically begins with the curator forming a list of objects that he or she wishes to put together, similar to a wishlist. Then, he would sketch plans to accommodate the objects on the list to determine whether such a list is feasible given the available space. While discussing plans with the curator or artist, he would also create study models of the exhibition and determine some of the items that must be constructed. Even though this may not be a common practice at other galleries, the MIT List Visual Arts Center has its own wood shop, and Mr. Lloyd is used to making furniture, such as partition walls, benches, and studs, customized for exhibitions. In addition to the exhibition designing process, we

also discussed approaches for evaluating the design of exhibitions. According to Lloyd, observing is the most common strategy he uses. According to his observation, people opt to visit the gallery for completely different purposes; therefore, it is difficult to develop uniform standards for the design. Still, the design of the exhibition does change how people navigate through the spaces in addition to other types of interactions occurring inside the gallery space.
3.4 Survey on Museum-Goers

3.4 Survey on Museum-Goers

In addition to interviewing professionals who work in relevant fields, I also designed a survey to collect common museum-goers' perspectives. The survey covers questions on their past museum visiting, their viewpoint, and their experience with virtual museums and museum experiences delivered in VR. After a pilot test of 11 participants, the survey was revised and published on the internet. In the end, 26 responses were collected.

In addition to collecting demographic information, the survey is composed of three sections: "experience of visiting art museums and galleries," "your personal museum experience," and "experience of using virtual reality applications." Some of the questions are listed below, while a complete survey can be found in the appendix:

Section 1:

- How often do you visit an art museum or gallery?
- How likely will you be motivated by the following reasons to visit art museums or galleries?
- What are some other motivations for visiting art museums or galleries that are not listed above?
- What kind of preparation work do you do before visiting an art museum or gallery?
- How do you usually receive news or information about art museums, galleries, and their exhibitions?
- How often do you do the following things when you are visiting art museums or galleries?
- When you are evaluating the success or not of your visit to an art museum or gallery, how important are the following factors?

Section 2:

- What are some of your favorite art museums or exhibitions

and why?

Have you ever used or experienced any online museum or virtual tours of museums (such as Google Art and Culture or Panoramic Palace Museum)?

If you have used or experienced museums' online exhibitions or virtual tours, could you list some of the ones that leave you a strong impression?

Section 3:

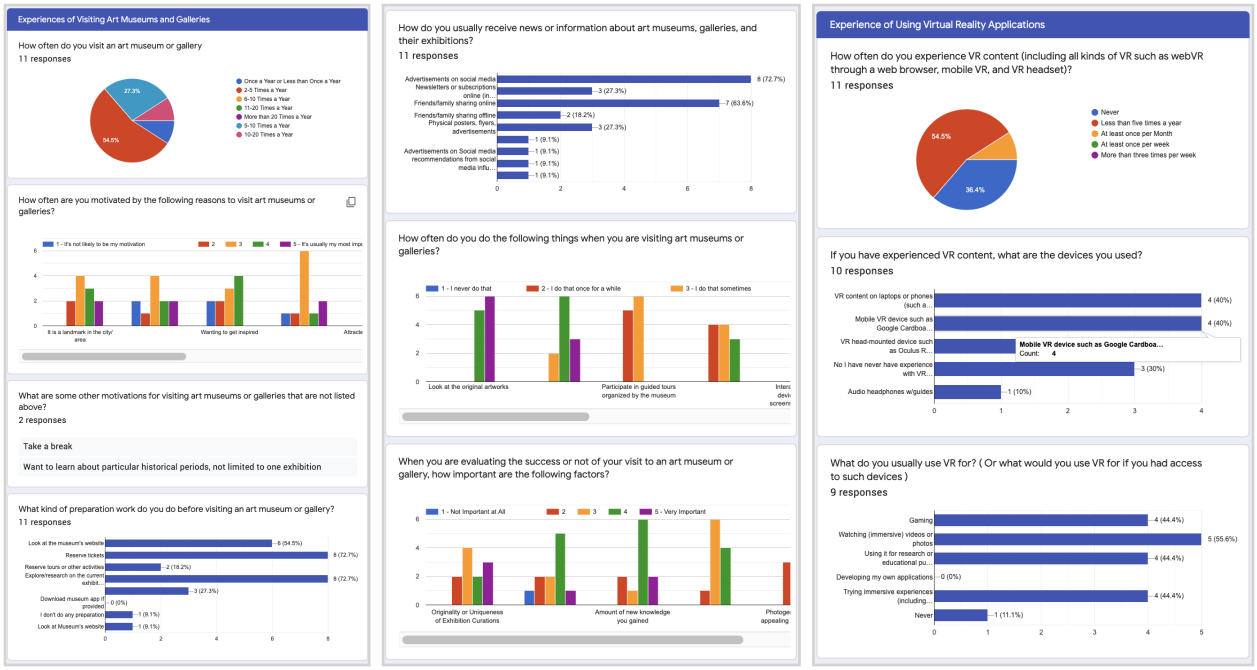
How often do you experience VR content on average (including all kinds of VR such as webVR through a web browser, mobile VR, and VR headset)?

If you have experienced VR content, what are the devices you have used?

Have you ever experienced an exhibition in VR or VR content as part of an exhibition in an art museum/gallery? If so, what is your feedback?

Most of the survey questions are designed as close-ended ordinal or nominal questions to reduce the cognitive burden of the participants. Moreover, several optional open-ended questions are asked to learn more about the details behind the participants' viewpoints. After the pilot test, the survey was shortened to promote the response rate and was then published using an on-response sampling approach. It was sent to school mail lists and social media, which is anticipated

Example of results from the pilot test



to result in a biased representation of the population. While analyzing the data collected from the survey, such potential bias was considered.

According to the survey, 62.1% participants did not have experience with any type of virtual museums and online exhibitions, and 35.1% participants did not have experience with any type of VR device. When asked which type of VR device the participants have used, the result was almost equally distributed between WebVR, mobile VR, and a head-mounted device.

According to the survey result, most participants have used VR as part of a museum visiting experience, and of those who did, the most frequent comment is that using VR in public spaces such as museums makes people feel uncomfortable, vulnerable, and isolated. Other concerns that have been mentioned in the response include the long wait time and low-quality content. Below are some interesting quotes from the survey:

"It would be annoying if there are a lot of people because of wait time. I think problems right now is how accessible is vr for all participants. It is still pretty hard to let everyone use it"

"... mostly use VR in pre visit research. Occasionally use on-site VR tech, frequently prefer to go without it in favor of focusing on the pieces in a collection that interest me rather than being led through an exhibit"

"It's great when I have visited the place and use the virtual tool to remember what I've seen"

4 CASE STUDIES

4.1 Case Study I—Museum of Fine Arts in Boston's Asian Art Collection

4.1.1 Overview

In parallel with the early research on the background and history of museums and virtual museums specifically, this thesis also begins with a case study of building a VR exhibition for selected objects from the Asian Art collection at the Museum of Fine Arts (MFA) in Boston. The Asian Art collection contains more than 100,000 objects, including paintings, prints, sculptures, ceramics, metalwork, and other art forms from Japan, China, Korea, South, Southeast Asia, and the Islamic world[31]. Among these subdivisions, the Japanese Art collection is one of the finest outside of Japan.

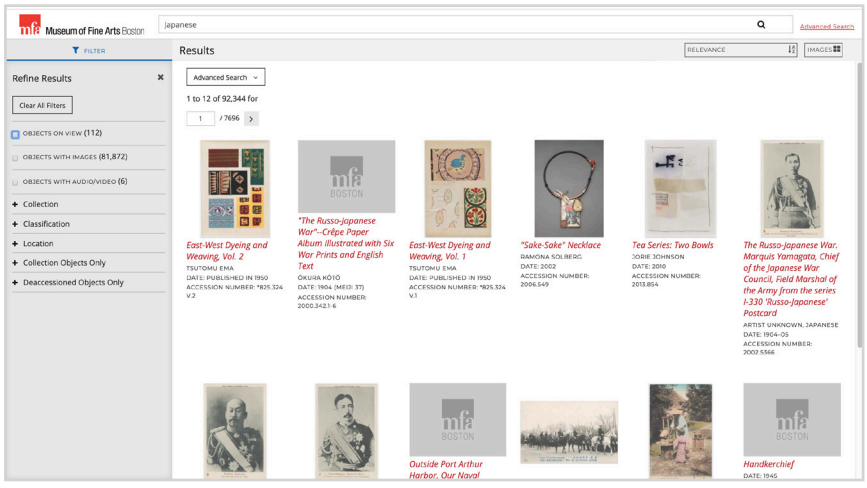
Since MFA publishes information about their collection on their "collection" webpage[32], I began the case study by reviewing the database and identifying interesting objects.

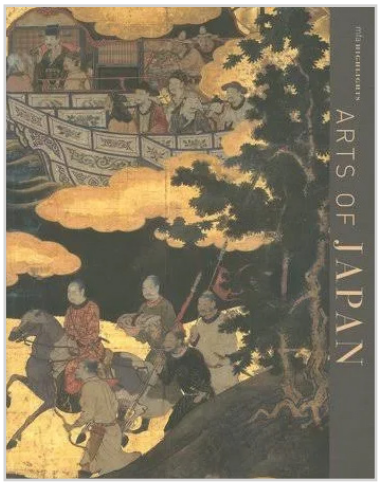
31
MFA Asian Art Collection: https://www.mfa.org/collections/asia

32
MFA Collection Page: https://collections.mfa.org/collections

Left: MFA Collection Webpage (Source: see above)

Right: ARTS OF JAPAN: MFA Highlights (Source: https://www.amazon.com/Arts-Japan-Highlights-Anne-Morse/dp/0878467149)





Upon reading about the description of each object, I attempted to summarize the information and created five categories. Those

categories essentially covered the written description of any objects, even though most would be missing for most entries.

Another source of information is the Arts of Japan: MFA Highlights, which provides an introduction to the Japanese Art collection at MFA and descriptions of some of the most famous pieces. In addition, MFA also launched a Youtube channel, which offers talks about its art.

4.1.2 Exhibition Content

With the rough idea of displaying different forms of artworks from the Edo period, I selected five objects from the collection: a screen painting, a hanging painting, a small ceramic figure, a box with a drum inside, and a buddha sculpture. As the next step, I created a digital archive containing their textured models, photos, and metadata. The textured mesh model was created via photogrammetry, while the other information was collected from MFA's website, Youtube channel, and printed catalog.

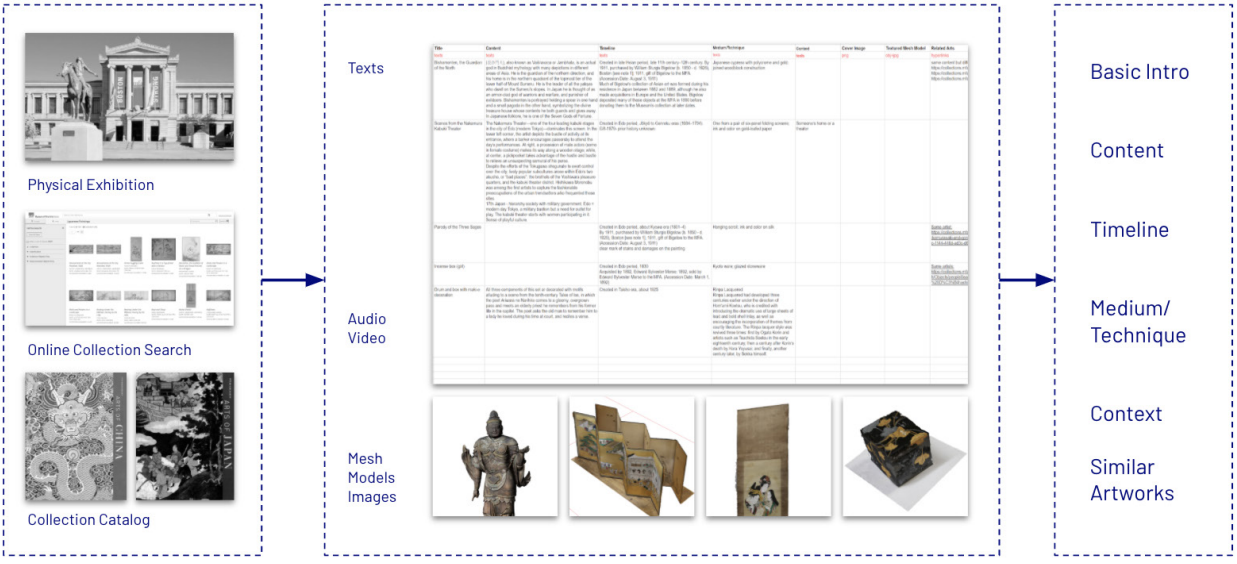
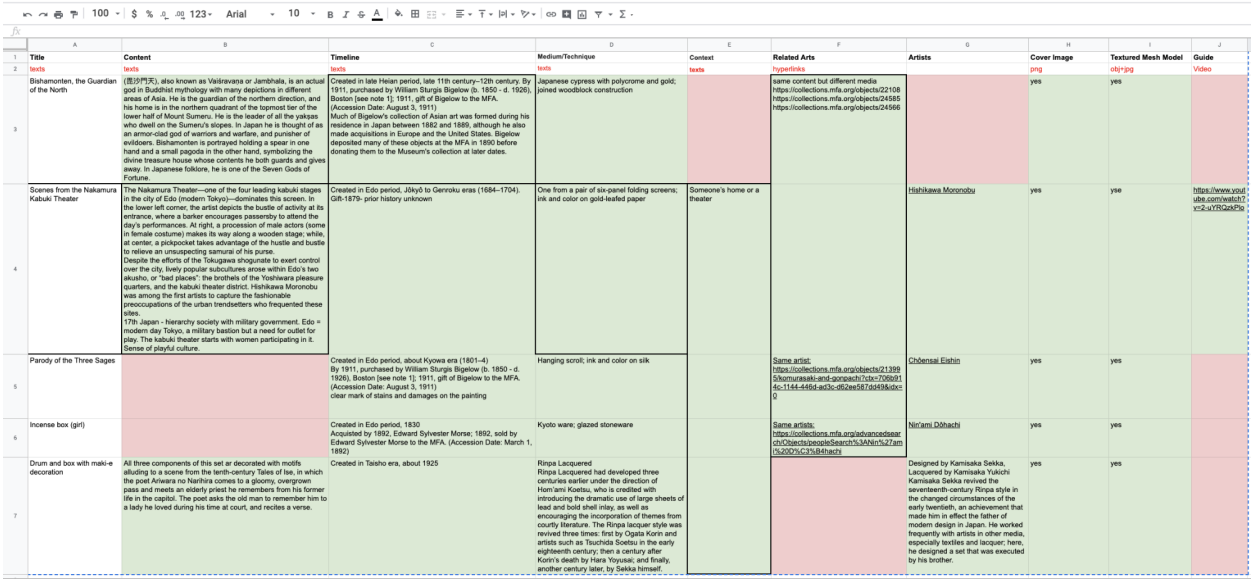


Diagram of the data collection process

Upon reading about the description of each object, I attempted to summarize the information and created five categories. Those categories essentially covered the written description of any objects, even though most would be missing for most entries.

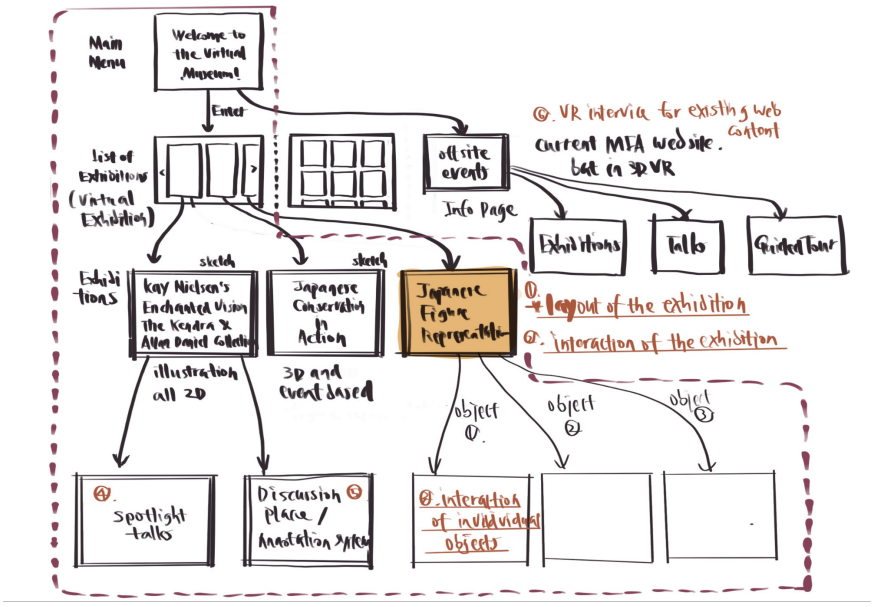


Title	Content	Timeline	Medium/Technique	Context	Related Arts	Artists	Cover Image	Textured Mesh Model	Guide
texts	texts	texts	texts	texts	hyperlinks		png	obj+jpg	Video
Bishamonten, the Guardian of the North	(毘沙門天), also known as Vaiśravaṇa or Jambhala, is an actual god in Buddhist mythology with many depictions in different areas of Asia. He is the guardian of the northern direction, and his home is in the northern quadrant of the topmost tier of the lower half of Mount Sumeru. He is the leader of all the yakṣas who dwell on the Sumeru's slopes. In Japan he is thought of as an armor-clad god of warriors and warfare, and punisher of evildoers. Bishamonten is portrayed holding a spear in one hand and a small pagoda in the other hand, symbolizing the divine treasure house whose contents he both guards and gives away. In Japanese folklore, he is one of the Seven Gods of Fortune.	Created in late Heian period, late 11th century–12th century. By 1911, purchased by William Sturgis Bigelow (b. 1850 - d. 1926), Boston [see note 1]; 1911, gift of Bigelow to the MFA. (Accession Date: August 3, 1911) Much of Bigelow's collection of Asian art was formed during his residence in Japan between 1882 and 1889, although he also made acquisitions in Europe and the United States. Bigelow deposited many of these objects at the MFA in 1890 before donating them to the Museum's collection at later dates.	Japanese cypress with polycrome and gold; joined woodblock construction		same content but different media https://collections.mfa.org/objects/22108 https://collections.mfa.org/objects/24585 https://collections.mfa.org/objects/24566		yes	yes	
Scenes from the Nakamura Kabuki Theater	The Nakamura Theater—one of the four leading kabuki stages in the city of Edo (modern Tokyo)—dominates this screen. In the lower left corner, the artist depicts the bustle of activity at its entrance, where a barker encourages passersby to attend the day's performances. At right, a procession of male actors (some in female costume) makes its way along a wooden stage; while, at center, a pickpocket takes advantage of the hustle and bustle to relieve an unsuspecting samurai of his purse. Despite the efforts of the Tokugawa shogunate to exert control over the city, lively popular subcultures arose within Edo's two akusho, or "bad places": the brothels of the Yoshiwara pleasure quarters, and the kabuki theater district. Hishikawa Moronobu was among the first artists to capture the fashionable preoccupations of the urban trendsetters who frequented these sites. 17th Japan - hierarchy society with military government. Edo = modern day Tokyo, a military bastion but a need for outlet for play. The kabuki theater starts with women participating in it. Sense of playful culture.	Created in Edo period, Jōkyō to Genroku eras (1684–1704). Gift-1879- prior history unknown	One from a pair of six-panel folding screens; ink and color on gold-leafed paper	Someone's home or a theater		Hishikawa Moronobu	yes	yse	https://www.youtube.com/watch?v=2-uYRQzkPlo
Parody of the Three Sages		Created in Edo period, about Kyowa era (1801–4) By 1911, purchased by William Sturgis Bigelow (b. 1850 - d. 1926), Boston [see note 1]; 1911, gift of Bigelow to the MFA. (Accession Date: August 3, 1911) clear mark of stains and damages on the painting	Hanging scroll; ink and color on silk		Same artist: https://collections.mfa.org/objects/213995/komurasaki-and-gonpachi?ctx=706b914c-1144-446d-ad3c-d62ee587dd49&idx=0	Chōbunsai Eishin	yes	yes	
Incense box (girl)		Created in Edo period, 1830 Acquisted by 1892, Edward Sylvester Morse; 1892, sold by Edward Sylvester Morse to the MFA. (Accession Date: March 1, 1892)	Kyoto ware; glazed stoneware		Same artists: https://collections.mfa.org/advancedsearch/Objects/peopleSearch%3ANin%27ami%20D%C3%B4hachi	Nin'ami Dōhachi	yes	yes	
Drum and box with maki-e decoration	All three components of this set ar decorated with motifs alluding to a scene from the tenth-century Tales of Ise, in which the poet Arwara no Narihira comes to a gloomy, overgrown pass and meets an elderly priest he remembers from his former life in the capitol. The poet asks the old man to remember him to a lady he loved during his time at court, and recites a verse.	Created in Taisho era, about 1925	Rinpa Lacquered Rinpa Lacquered had developed three centuries earlier under the direction of Hom'ami Koetsu, who is credited with introducing the dramatic use of large sheets of lead and bold shell inlay, as well as encouraging the incorporation of themes from courtly literature. The Rinpa lacquer style was revived three times: first by Ogata Korin and artists such as Tsuchida Soetsu in the early eighteenth century; then a century after Korin's death by Hara Yoyusai; and finally, another century later, by Sekka himself.			Designed by Kamisaka Sekka, Lacquered by Kamisaka Yukichi Kamisaka Sekka revived the seventeenth-century Rinpa style in the changed circumstances of the early twentieth, an achievement that made him in effect the father of modern design in Japan. He worked frequently with artists in other media, especially textiles and lacquer; here, he designed a set that was executed by his brother.	yes	yes	

Screenshot of the curated data set

4.1.3 Design of the VR Exhibition

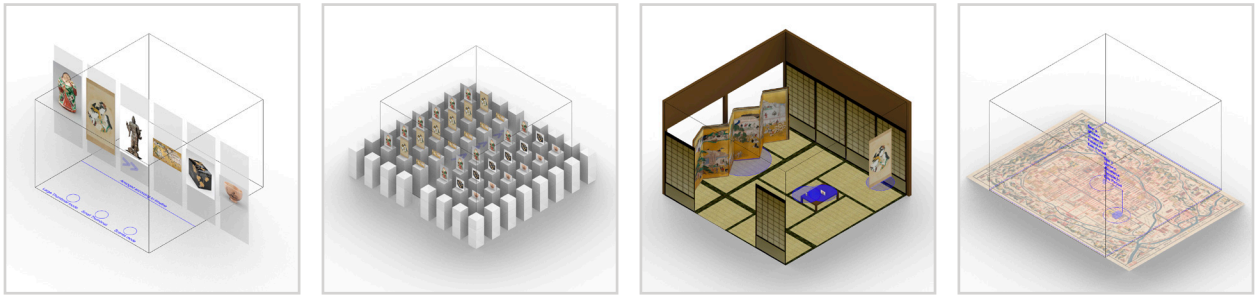
I began the design of the VR exhibition by drafting the wireframe of the application, as designers typically do when designing new websites.



The exhibition opens upon a welcome screen and then displays a list of exhibitions that can be experienced in VR. Each of the exhibitions should have a specific theme and include further activities, such as spotlight talks and discussion panels. In addition, the exhibitions also include links to a space dedicated for each object.

In parallel with figuring out the system, I also designed the individual scenes. Some questions that were raised during the process are as follows:

1.How generic and adaptative must the system be?
2.How can the environment of those exhibition spaces be designed?
3.How much information is needed to be contained for each experience?



Screenshot of some design drafts in Rhino

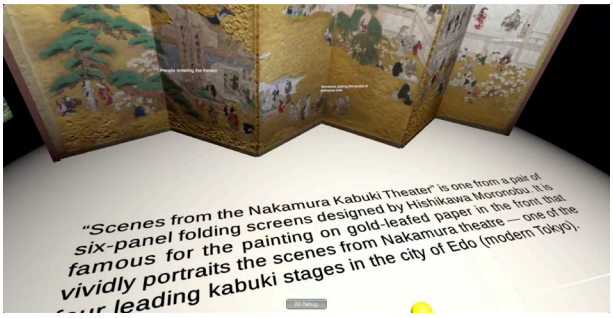
In the end, four scenes were designed and implemented with Unity3D and SteamVR and tested on an HTC Vive headset. Below are some screenshots of the VR experience, and a screen capture could be found at https://vimeo.com/390250822 (password: virtualdesign).

Screenshots of the gameplay

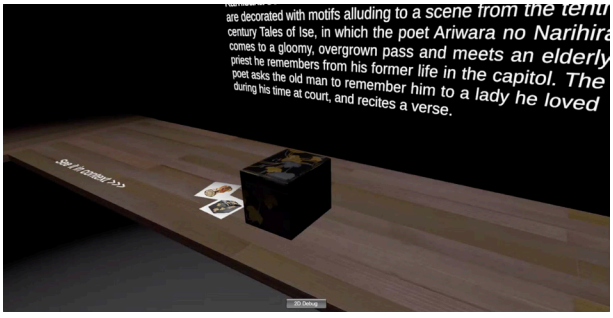
Scene 0

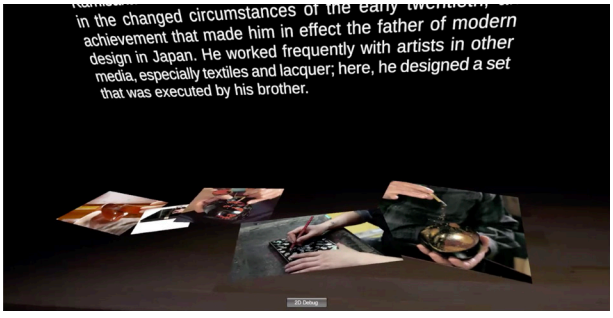
Scene 1

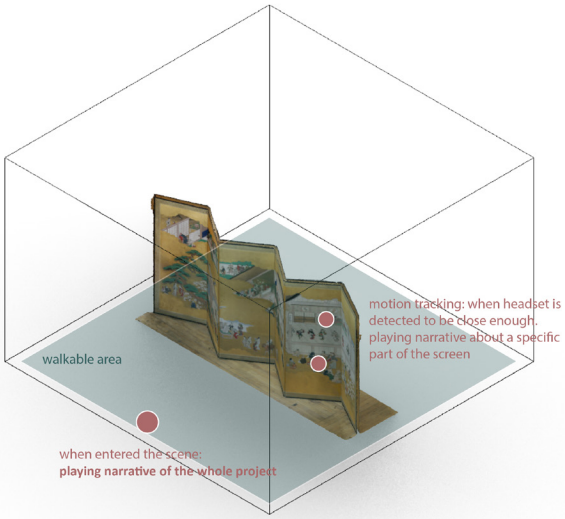
Scene 2

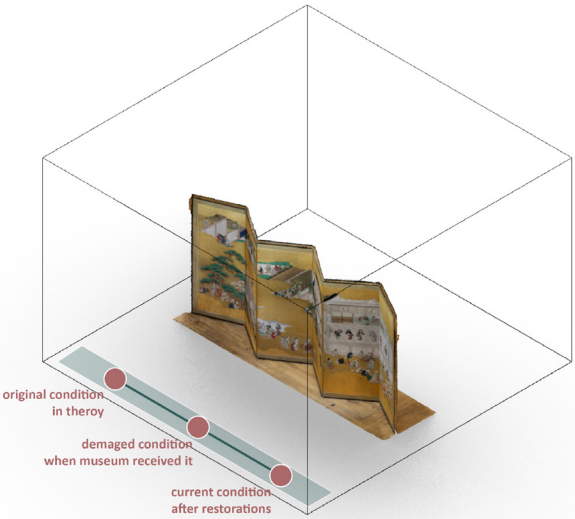


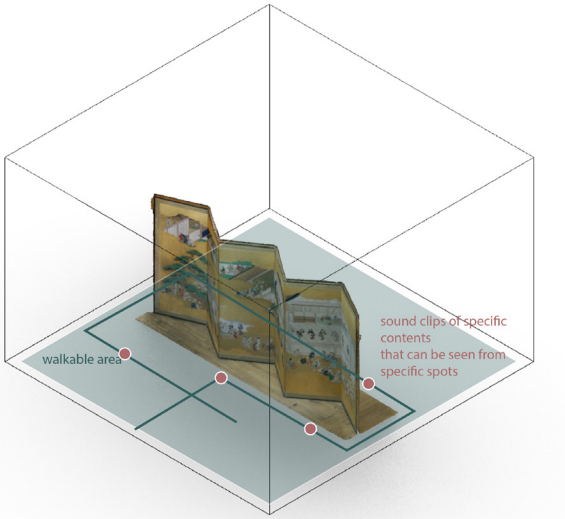
Scene 3

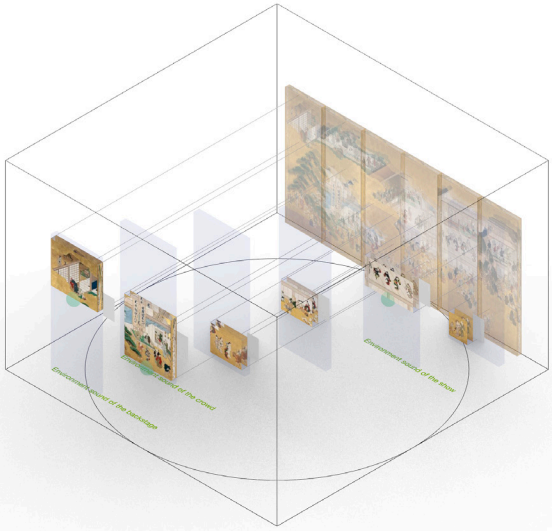


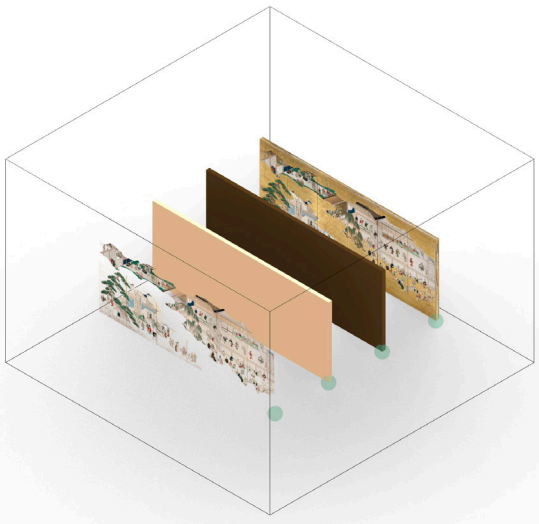


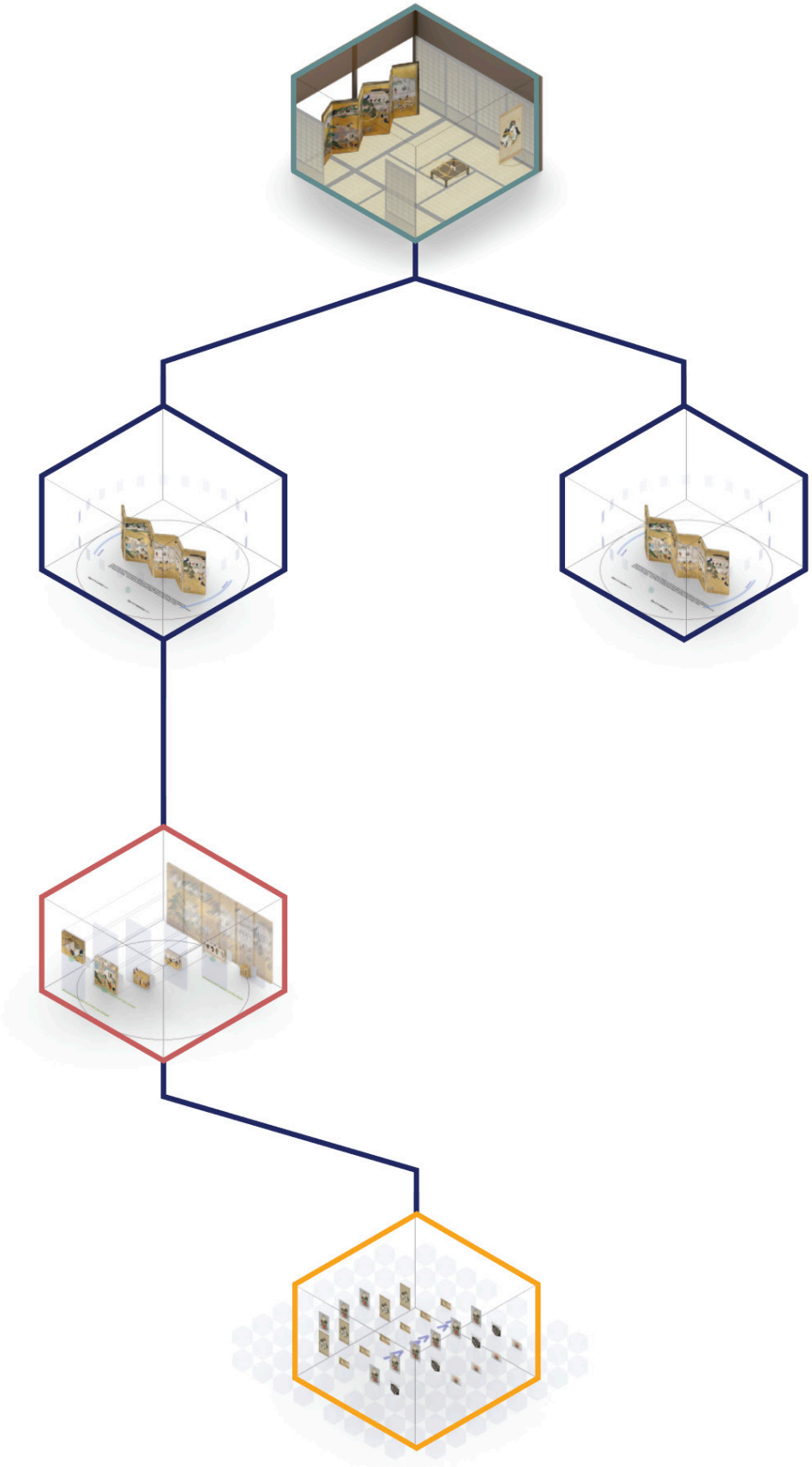

motion tracking: when headset is
detected to be close enough,
playing narrative about a specific
part of the screen
walkable area
when entered the scene:
playing narrative of the whole project


original condition
in theroy
demaged condition
when museum received it
current condition
after restorations


sound clips of specific
contents
that can be seen from
specific spots
walkable area







4.2 Case Study II—Art of Memory

4.2.1 Overview

The "Art of Memory" is an art project developed collaboratively by Charisse Foo (Cornell University, B.Arch '18) and me starting in the spring of 2019[33]. It is based on a 12-day travel supported by the Robert James Eidlitz Travel Fellowship[34] (2018–2019) issued by the Department of Architecture at Cornell University. Within the 12 days, we traveled to four Italian towns that have been indelibly changed by natural disasters: Pompeii, Catania, Poggioreale, and Gibellina, each of which embodies a unique approach toward destruction and preservation. The "perfectly" preserved ruins of Pompeii are set against the bustling capital of Catania, the ghost town of Poggioreale, and the crumbling modernist art installations of Gibellina. The project explores the notion of architectural memory with the impact of natural disasters and considers ways of representing and interpreting those collective memories.

33
The Art of Memory: https://www.behance.net/gallery/85728977/The-Art-of-Memory

34
Robert James Eidlitz Travel Fellowship (2018-2019): https://aap.cornell.edu/academics/architecture/about/fellowships

We developed a comprehensive collection of various types of documentations during the trip in addition to a series of explorations in the format of drawings and collages based on our observations of each location during the trip. The documentations and explorations were then transformed into two exhibitions: a one-week exhibition at the studio space of the Cornell University School of Architecture, Art, and Planning in New York City during September 2019[35] and a two-month exhibition at the exhibition space of MIT Rotch Library from January to March 2020[36].

35
Art of Memory" NYC Exhibition in September 2019: https://aap.cornell.edu/news-events/charisse-foo-and-yichen-jia-art-memory

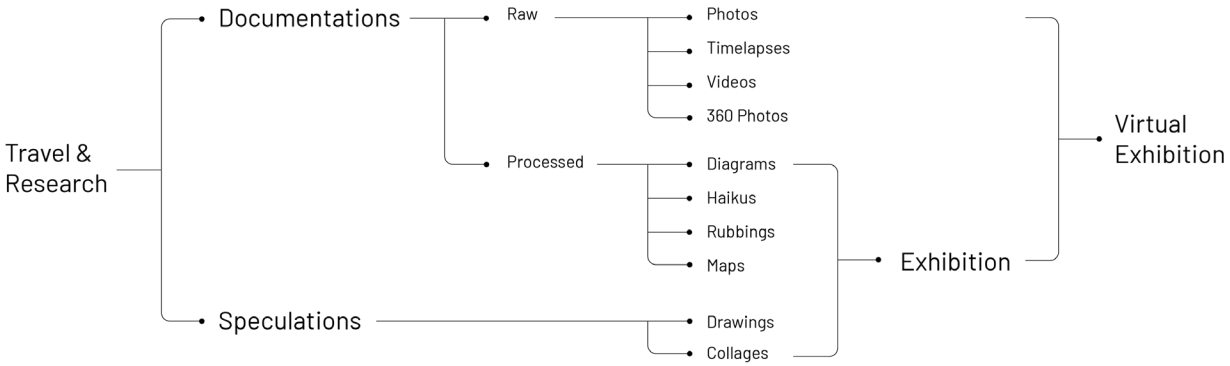
36
"Art of Memory" MIT Rotch Library Exhibition from January to March 2020: https://libraries.mit.edu/exhibits/exhibit/memory/

Why It is Selected as a Case Study

The project is selected as a case study of this thesis because I was involved in the project as one of the creators (artist), curators, and exhibition designers and therefore have a deep understanding of the project. The background knowledge and additional materials of how each piece of work is created and evolved and how they relate to one another conceptually are aspects I find truly important when curating an exhibition. Those are factors that I am missing when I curate the MFA Asian Art collection VR exhibition but have access to here. Therefore, even though the "artworks" from this project are not as recognized as the artworks normally collected by museums, I still wish to use them as part of this thesis.

Moreover, since all the materials for this project were captured and developed by Charisse Foo and me, there is no copyright issue when I use it as part of my thesis research.

4.2.2 Content of the Exhibitions



Documentations
During the trip, we took photos, time-lapses, videos, and panoramic photos to record our experiences and observations. In addition, we each produced 12 drawings and 12 corresponding haikus, one for each day. These 24 haikus and drawings capture the immediacy of our travel experience; short, provocative, and whimsical, these visual and textual reflections serve as both artifacts from the trip and starting points for further exploration. They have been revised and updated since our return and are accompanied by 12 maps that trace our daily travel route.

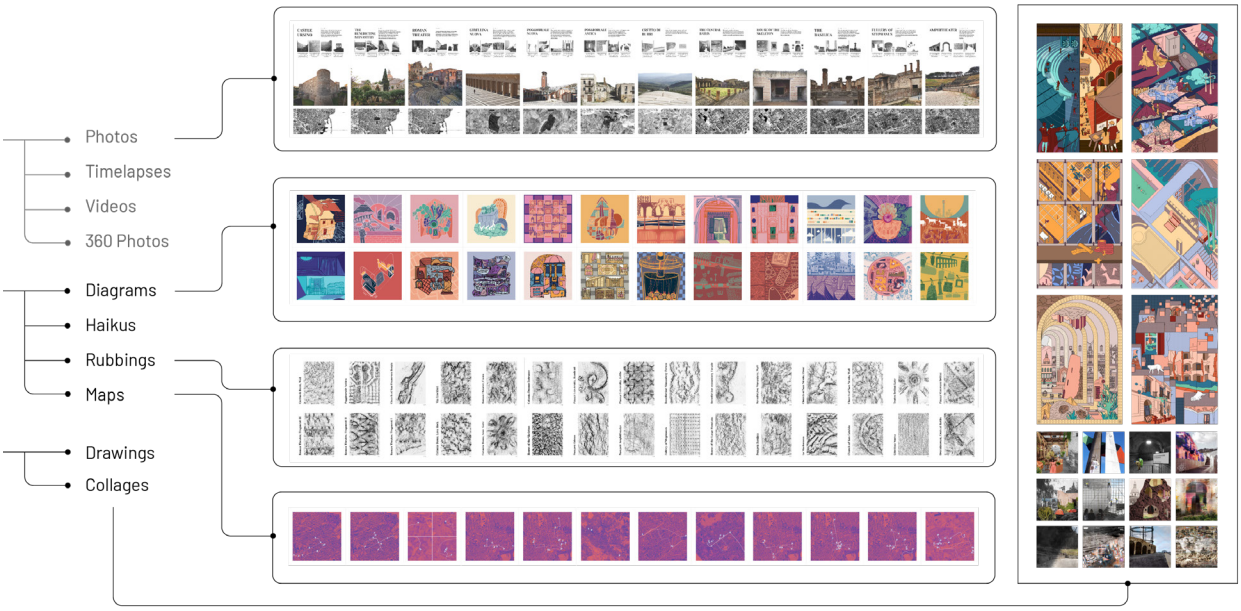
In the tradition of gravestone rubbing and surrealist frottage, our 30 rubbings of sites from Sicily to Naples form a catalog of textures, lifted from their context and flattened into the mark-making of the drawing. They are accompanied by on-site photos and descriptions.

Speculations
Drawn after our trip, these six sets of architectural illustrations speculated upon six sites, each representative of a possible future scenario of preservation, rehabilitation, restoration, or reconstruction. How might these complex, historical places age? Might they experience a rebirth or perhaps an afterlife?

Report[37]

37
"Art of Memory" report: https://www.blurb.com/b/9919013-the-art-of-memory

A compilation of our project is available in book form on Blurb. The 330-page book contains extended write-ups on our 12 selected sites, unpublished sketches from our trip, and everything else displayed in the exhibition.

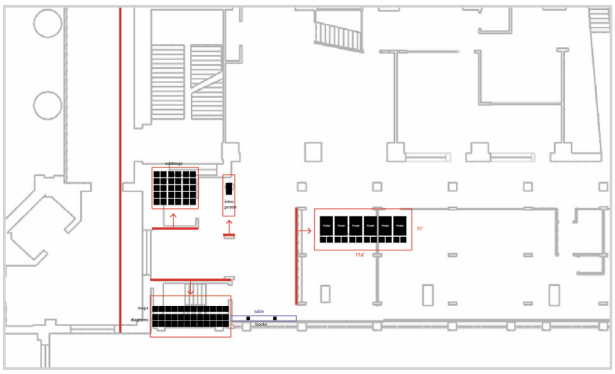


4.2.3 Design of the Physical Exhibition

When we were designing the exhibition for the Cornell AAP New York City studio, we began by arranging all the pieces into groups and fitting those groups into the display panels. We looked at the total surface areas that could be covered by our artworks and arranged the artworks accordingly based on their sizes. Moreover, we considered the circulation of the space and arranged different sections of the exhibition so that the conceptual sequence of the content would match the visiting flow. During the process, we created additional posters and labels to introduce the exhibition and describe the content of each section. What we planned to display at the start did not end up covering all the surfaces after we arranged everything, so we reviewed our documentation and curated a series of photographs grouped into specific themes to fill the empty space and complete the design.

As we designed the exhibitions for both the Cornell AAP New York City studio and the Rotch Library exhibition space, we began by reviewing the plans of the spaces and arranged the artworks

accordingly based on their sizes. In addition, we considered the circulation of the space and arranged different sections of the exhibition so that the conceptual sequence of the content would match the visiting flow. Most of the time, however, we needed to make compromises due to limitations of the physical spaces.

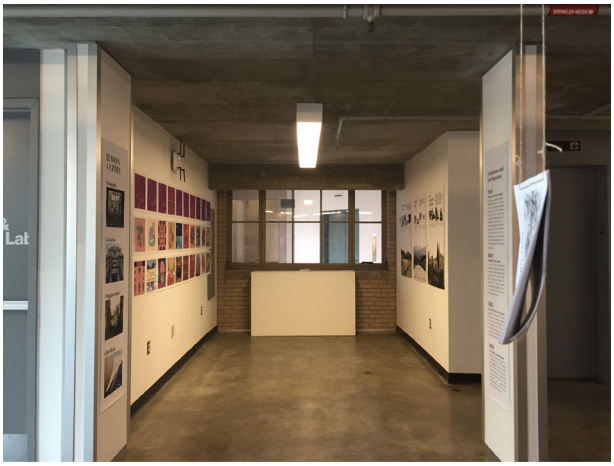


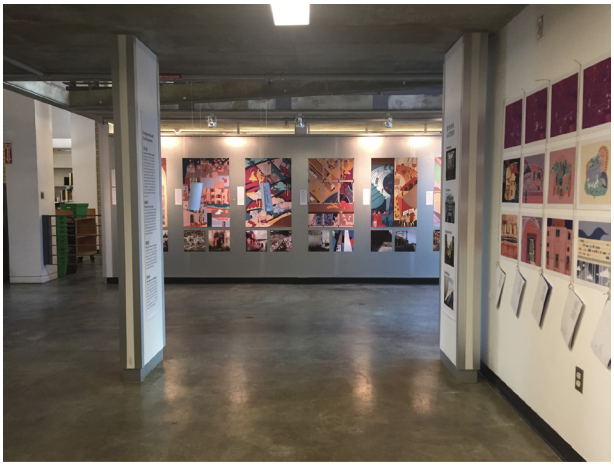
The design of the Rotch Library Gallery was quite different because its exhibition space is considerably smaller than the Cornell AAP studio space, so we initiated the exhibition planning by calculating the size of each wall within the exhibition space and selected artworks to be displayed on them based on their dimensions, therefore maximizing the total number of artworks we could showcase. Due to the physical constraints, we needed to be selective and determine which were the most important pieces to display. For example, we did not display all the site posters as we had planned because there was simply not enough space for them. In addition, we could not afford to consider the relationship between each component as much.

Left: Photos of "Art of Memory" Cornell AAP NYC Studio Exhibition

Right: Photos of "Art of Memory" MIT Rotch Library Exhibition

Photos of "Art of Memory" Cornell AAP NYC Studio Exhibition





Photos of "Art of Memory" MIT Rotch Library Exhibition

4.2.4 System Design of the Virtual Exhibition

When people design a virtual exhibition in VR, physical constraints are no longer a primary design consideration. Instead, designers can focus more on the artwork collection itself and the storytelling aspect of the exhibition.

Similar to the MFA VR exhibition, the Art of Memory VR exhibition was designed following an object-oriented method. As presented in the diagram below, the exhibition is divided into seven scenes, each with a different theme and collection of artworks embedded. Scene A is the starting scene, which contains links to all the other scenes. Scene B is primarily based on an interactive map, which showcases all the geographic information about the trip and the artworks. Scene C is a 3-D photo gallery, which contains selected documentations from the trip, including photos, panoramic photos, and time lapse videos. Scenes D, E, F, and G are scenes designed to display different types of artwork from the project, namely the daily route maps with diagrams and haiku, rubbings, and speculative drawings, respectively.

4.2.5 Scene Designs of the Virtual Exhibition

This section describes the design of each virtual exhibition scene in detail. Even though these scenes are designed for the "Art of Memory" VR exhibition, they could be transformed into templates and adapted to other exhibitions, as well.

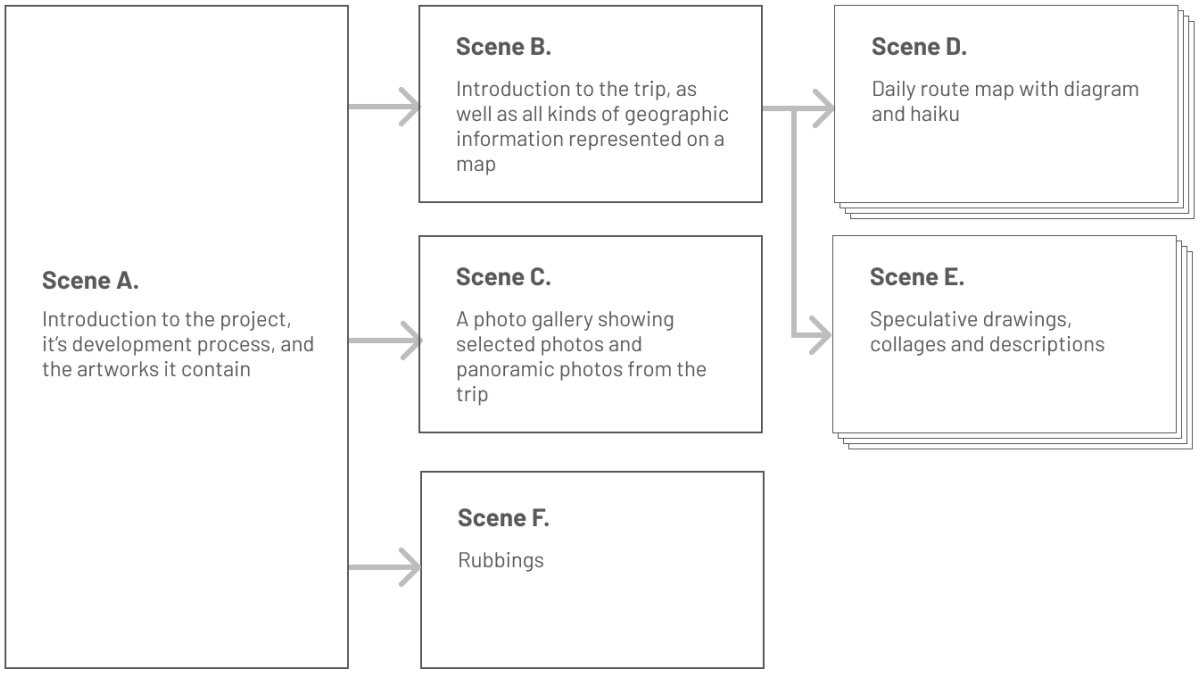


Diagram displaying different scenes and their relationship

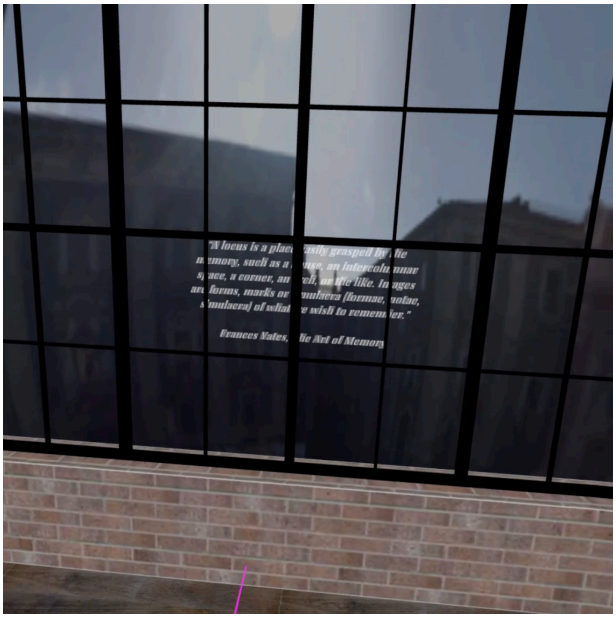
Scene A—Workspace that assemblies all relevant information

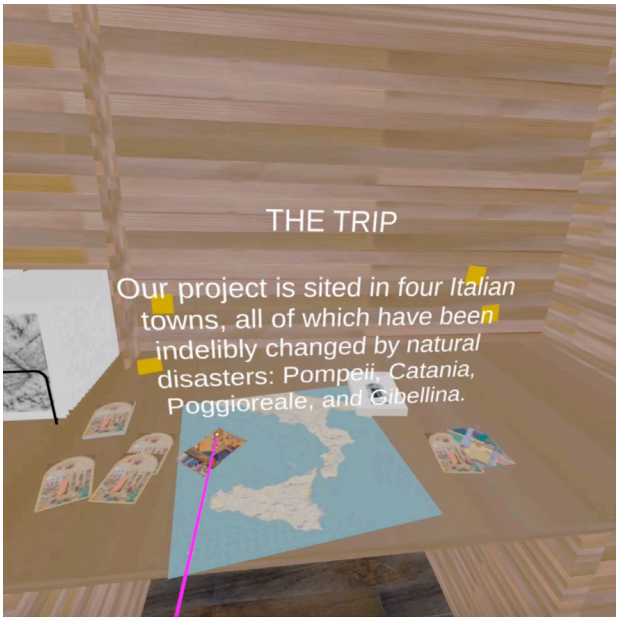
The exhibition begins with a scene that mimics a study and research space, which is proven to be a good scene that could link different formats of graphic contents together. The positions of each object indicate the designer's intention of their sequence to be explored based on how far they are from the starting position, which is where the chair is located and where the user should begin their exploration.

Visitors could interact with the scene using a laser pointer shooting from one of the controllers. When the laser pointer hovers over certain points, texts and objects might appear, therefore functioning as visual guidance to indicate the interactable elements within the scene.

Scene B—Trip History Made Visible on a Map

Since the project is based on a 12-day trip in Italy, much of its content is directly related to some geographic information. In this scene, three sets of artworks are presented: daily maps, site posters, and speculative drawings. In addition, our travel route and important geographic information about our sites, such as the location of two

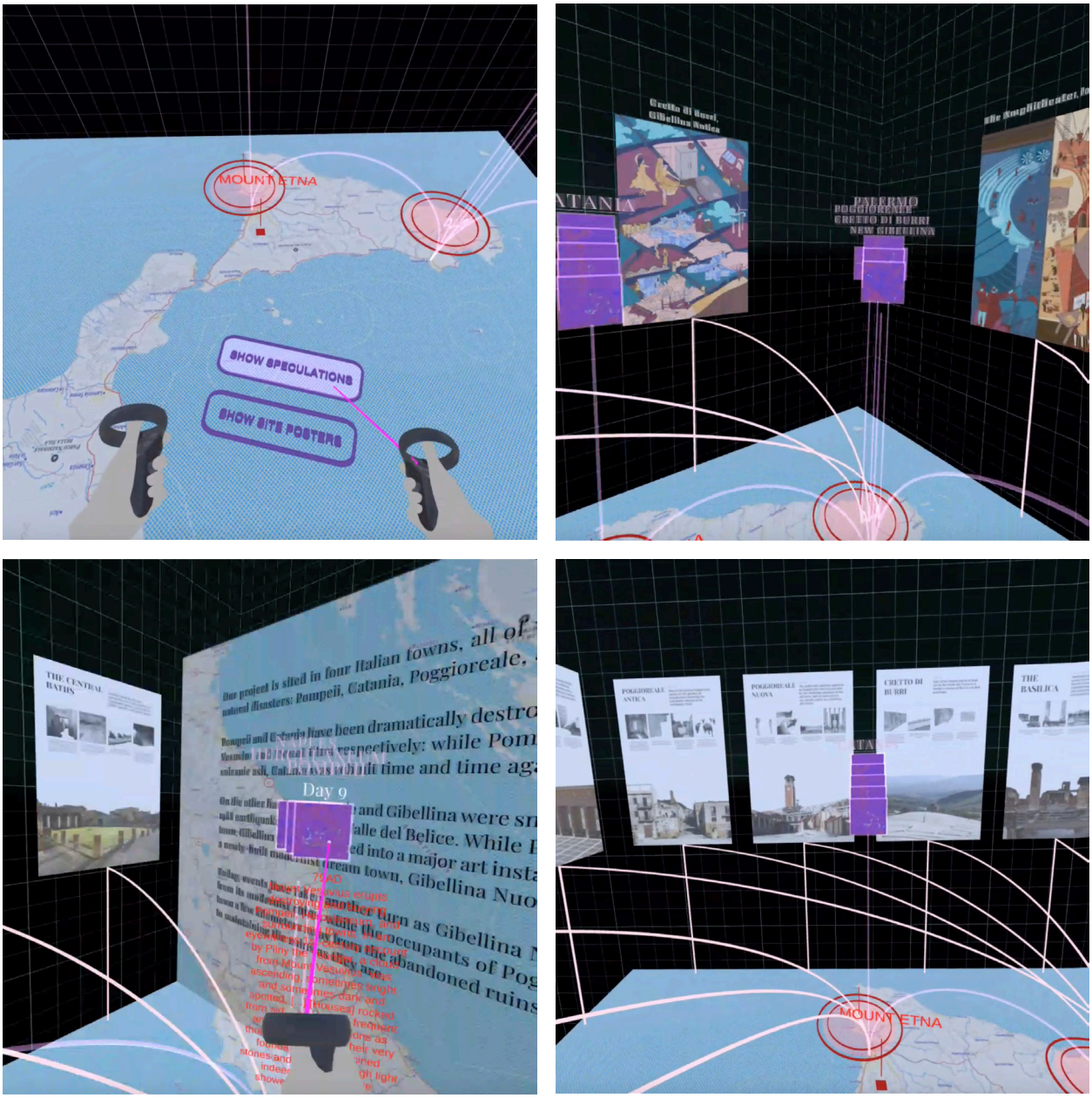




volcanoes and an earthquake, are also visualized on the map in a 3-D format.

In the prototype, I used a static image taken from Mapbox studio as the map. However, in the future, I want to integrate the Mapbox Unity Plug-in so that the map can be scaled and moved freely.

Scene C—Photo Gallery



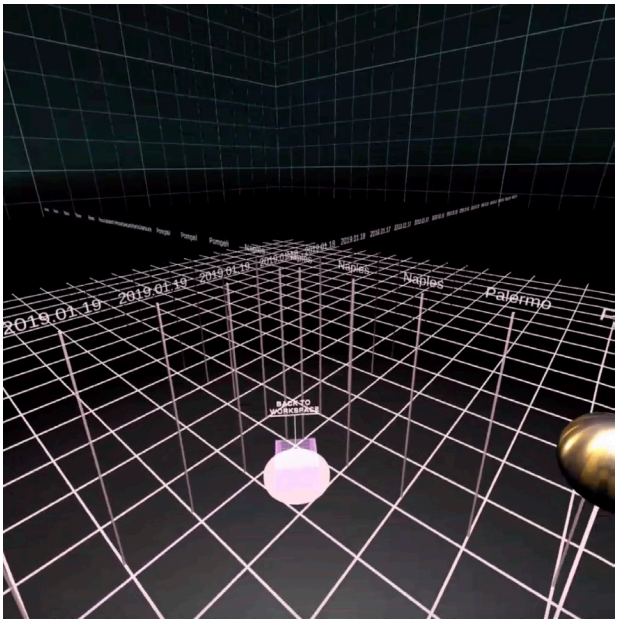
The photo gallery is meant to display photos, videos, and 360 photos we collected during the trip. Instead of highly curated content, it is supposed to showcase raw data and allow users to understand the trip without any re-interpretations of the artists, allowing them their own perspectives. The position of the images reflects the similarity between artworks and the time and location in which the photos are taken.

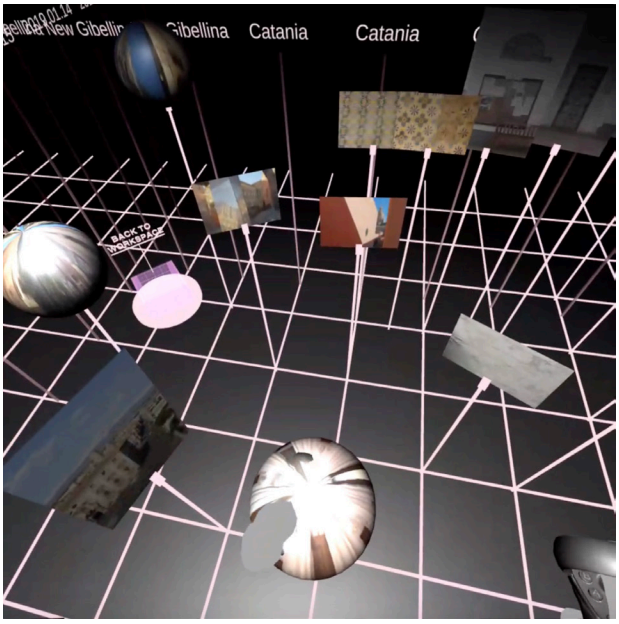
Because these photos are relatively not that important a part of the

exhibition, they are typically neglected in physical exhibitions due to space constraints. The early-stage materials, however, often allow visitors to view the working process of artists and allows them to understand the source of their inspiration.

In comparison with the design of other scenes, the photo gallery scene offers a relatively larger space for moving around. Therefore, it requires the user to move and use the controller rather than natural walking. Locomotion is not included as an option because it might disorient the user in this scene, in which everything looks similar at different locations.

The physical photo gallery in AAP NYC Exhibition, where photos are grouped by themes such as Volcano, walls, floors, thresholds, and arranged in a linear format horizontally to guide visitors. Photo credit: Charisse Foo

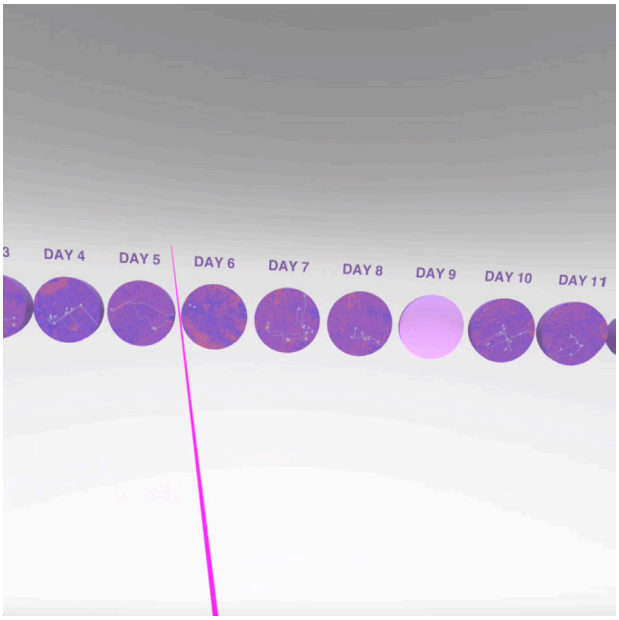




A set of 3-D UI elements and a spotlight follow the user as the user moves around. These are designed to provide more information about the displayed photos and provide a convenient means for users to navigate within the scene or between scenes of the exhibition. In addition, when the user moves about the scene, photos always rotate around their vertical axes so that they can face the users, thereby providing an optimized viewing experience.

Scene D—Daily Activity

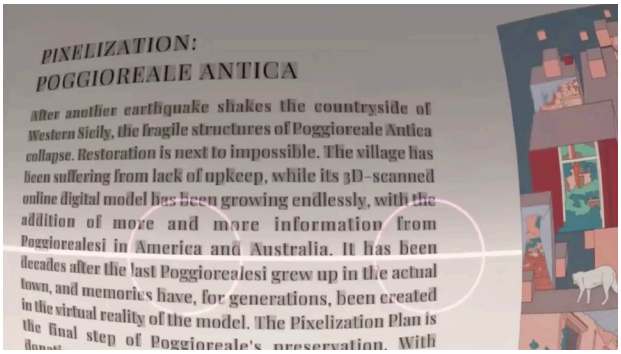
This scene is another map-based scene but focuses on the activities occurring on each individual day. With a daily route map covering the group, the scene also includes two diagrams and two haikus, which we developed to document the most memorable experience of that specific day. A 3-D timeline is created as well, which allows users to navigate between different days.

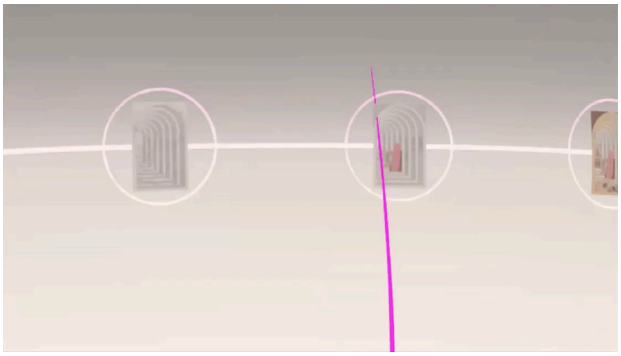


Scene E—Timeline of Speculative Drawing

This scene is created to show the creation process of individual speculative drawings. We have maintained a relatively detailed documentation of our drawing process through time lapse videos and snapshots. More importantly, we discovered during our physical exhibition that the creation process of artworks is something that the visitors, especially those with a design background, are often

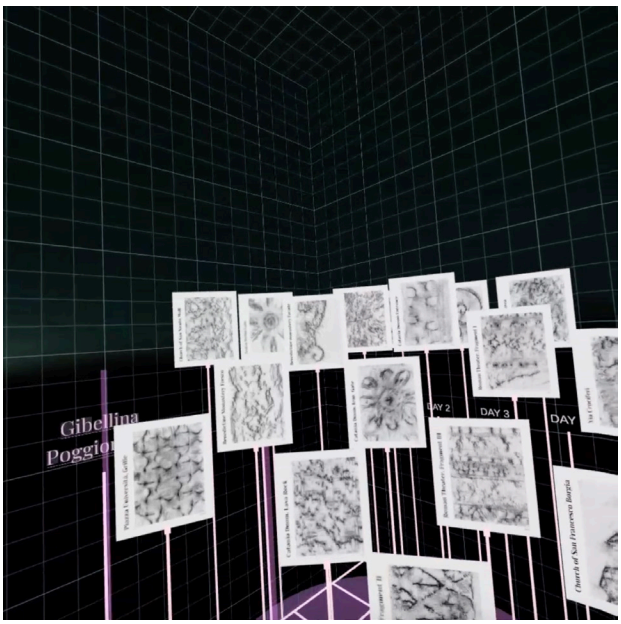
interested in and ask us about. This scene design allows visitors to closely examine the construction process and the reference we have used.

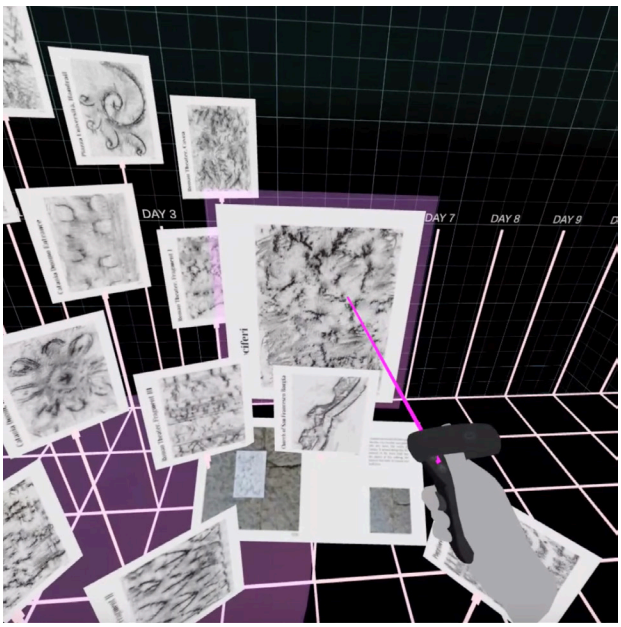




Scene F—Rubbings

Another set of documentation, rubbings, which we took from artifacts with interesting surface patterns, are presented in a setting similar to the photo gallery format. They are represented as a single image and located in the 3-D grid based on their location and date of creation. When pointed at by the laser pointer, images unfold to reveal more information about how that specific rubbing is created.





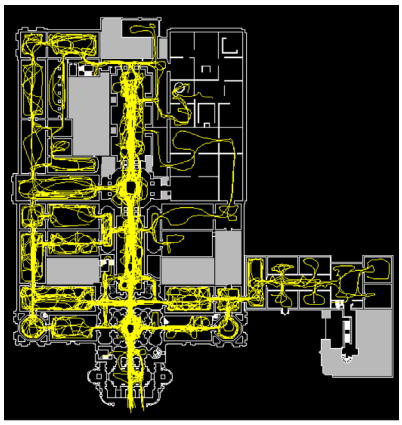
4.3 Design Evaluation

4.3.1 Existing Methods

The evaluation methods of such virtual exhibition or virtual museum designs could be viewed as a hybrid approach that draws references from both methods on evaluation museum experience and evaluation digital human-computer interface.

Observation

One common approach for museums to study the visitors' experience is to directly ask staff or researchers to observe the visitors' behavior. With the potential of being labor intensive, observation is one of the oldest strategies and remains one of the most commonly used.



Walking through the Tate
The yellow lines display the paths of visitors for the first 10 minutes after they enter the gallery (Source: Batty, et al., 1998)

Video and Audio Records

In addition, video records and voice records collected from cameras hanging on the ceiling and mixed among displayed objects are also utilized in more formal studies [8]. After being recorded, videos could usually be analyzed and transformed into other data formats. In 1995, researchers at the Centre for Advanced Spatial Analysis recorded 12 hours of visitors' movement in the Tate Museum in London. Visitors were tracked for 10 minutes after they entered the gallery, and this data was used to create the graph below.

Other Types of Sensors

Visitors' circulation inside the museum space is one of the most well-studied factors within this area. Determined jointly by visitors' previous interest and the design of the museum, this factor ultimately reveals what the visitors see, experience, and learn [26]. In addition to direct observation and video recording, a variety of sensors could be implemented to track people's behavior inside the museum's space to understand their experience. For instance, Bluetooth proximity detection is used to collect a large set of low spatial resolution data on visitors' sequential movements [27].

Post-Visit Questionnaire (VPQ and VEQ)

A visitor profile questionnaire (VPQ) was developed to collect the

same baseline information of all visitors who participated in the study. Observations and analyses from the video as well as voice records could usually be combined with post-visit questionnaires for visitors to complete on-site, in addition to more in-depth interviews [8].

A visitor experience questionnaire (VEQ) is another type of questionnaire that focuses more on open-ended questions. They are more difficult to answer and are therefore more costly but provide quantifiable data. When using VEQ, researchers must typically provide a working area to the participants and be on hand to help when needed [8]. Such questionnaires share much similarity with user surveys of experience with digital products, so many rules can be borrowed when designing the instrument.

Personal Meaning Maps (PMM)

When creating personal meaning maps (PMM), users are asked to write words or phrases that he or she associates with the topic of the exhibition or a certain object on a sheet of paper [8].

Interviews

The interviews, although more costly, allow researchers to explore the "why" behind the "what" they observed in the video and audio records [8]. Interviews could be more costly and time consuming than observation and require interviewers to plan ahead and consider time and environment. For instance, it may be necessary to find a sitting area and consider offering a cup of coffee and tea to the participants.

In addition to conducting the interview immediately after the visits, some studies focus on interviewing museum visitors over a much longer timeframe, mainly to understand their museum experience from an education perspective. Recollection studies are one of the major methods for studying the evidence of museum learning. Normally non-experimental, those studies are intended to reveal patterns rather than approval hypotheses [28].

4.3.2 Proposed Evaluation Method

Initially, the proposed design is planned to be evaluated by two different methods. The first method is a user test developed for the MFA case study mentioned above and is designed based on user experience study methods of

physical exhibitions [29]. To be more specific, users will be asked to spend a certain amount of time in the virtual exhibition. Their behaviors and path of navigation will be recorded, and they will be required to complete a survey after they are done with their virtual experience. In addition, a between-subject study to compare a physical exhibition and a virtual exhibition of the same content is planned.

However, due to the impact of COVID-19, MIT and its exhibition spaces are closed in mid-March 2020, and people are strongly encouraged to practice social distancing. As a result, the method of evaluation has shifted to adapt to this new situation. Since there is only a limited number of participants accessible to me, the experience procedure will be longer so that I can maximize the findings from each.

The experiment can be divided into four parts:

1. In the first part, a short questionnaire will be completed by participants to identify their past experience with VR and their background knowledge of the Art of Memory exhibition.

2. In the section part, after a short introduction of the possible interaction methods, participants will be invited to enter the VR exhibition. During this phase, while they experience the VR content, their viewport in the headset will be recorded and, in some cases, streamed. By streaming their viewport, I will be able understand what they are experiencing in real time and provide guidance to reduce frustration, which is used as a controlled parameter. The participants are asked to spend a maximum of 15 minutes inside the exhibition, and they may decide to leave at any time. During that time, the participants are encouraged to explore as much as they could.

3. Immediately after the experience, an interview is conducted with each participant. While there are several fixed questions prepared for the interview, it is loosely structured in an open-ended format. This provides an opportunity for the participants to provide general comments about their experience. During the interview, I also ask the participants to compare the two different interaction methods and locomotion methods.

4. In the fourth part, participants are asked to respond to the second half of the questionnaire. In the questionnaire, I provide the participant with a set of metrics, and they select

a score ranging from 1 to 5 for each evaluating metric for each scene.

4.3.3 Evaluation Results

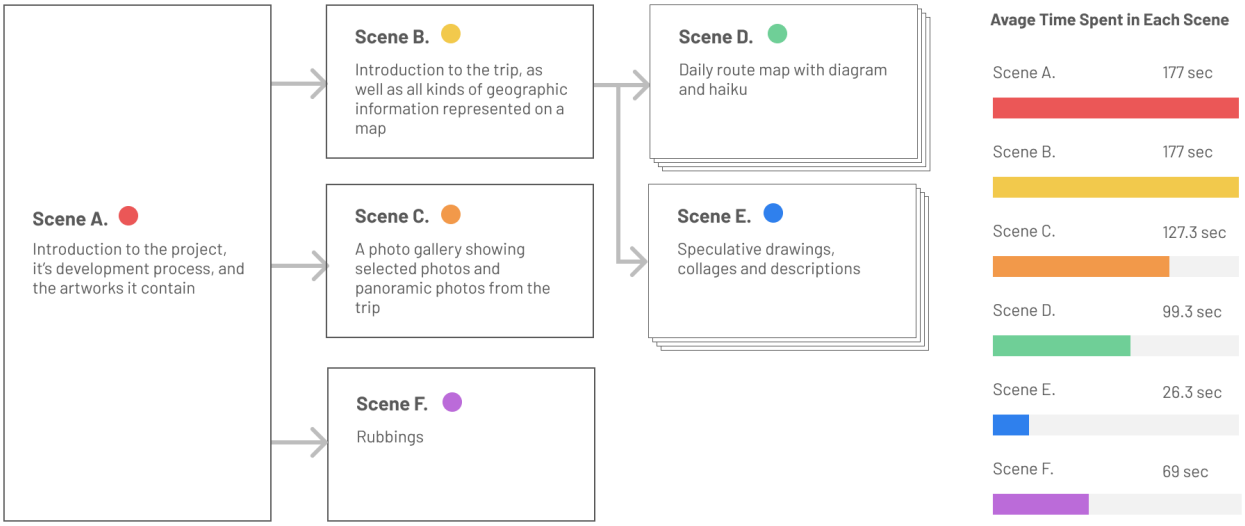
Participant Backgrounds

Each participant in the experiments has a different background, level of previous knowledge, and exhibition content. More importantly, since the experiments are conducted remotely, each participant has a different activity space set-up, therefore limiting and indicating their choice of interactions, which is proven to be extremely useful for making the design adaptive. Below is a summary of the report:

	Past Experience with VR	Previous Knowledge of the Exhibition	Activity Area (Estimate)	Standing or Sitting
Participant #1	0–2 times per year	Have viewed materials of the exhibition	6 feet*12 feet	Standing
Participant #2	More than 3 times per year	Have heard of the exhibition	4 feet*4 feet	Standing to sitting
Participant #3	More than 3 times per year	Have visited the exhibition	Small L-shape	Standing

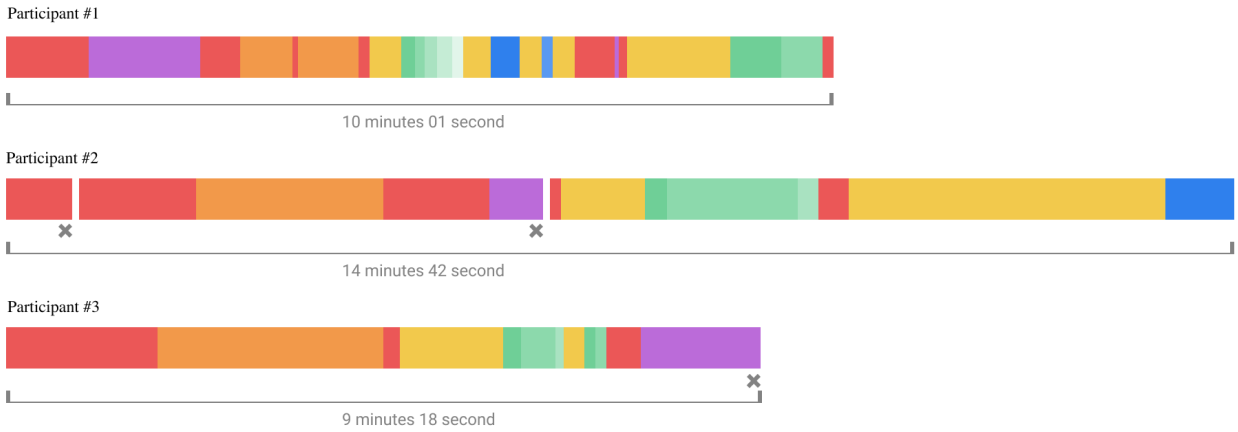
Path of Navigation

Adapted from a standardized user research method for websites and



mobile applications, I considered the timespan that each participant spent in each scene and how they shifted from one to another. All the scenes that comprised the VR experience and their connection are depicted in the diagram below: the arrow indicates the ability to transit from one scene to another.

Structure of different scenes and average time participants spend in each



According to the analysis below, it can be seen that all participants experienced frequent jumps between different scenes and entered the same scene more than once. This is potentially due to the lack of indication as to whether the re-entered scene was entered previously.

Color-coded diagram displaying each participant's behavior of staying in different scenes and jumping between scenes

Information Consumption

Based on the comparison between the amount of information in different scenes, one can see that different types of information are rather unequally distributed. In addition to the fact that Scene D and Scene E have significantly less information than the other scenes because they are designed to showcase single artworks rather than a collection, the participants tended to remain longer in the scenes that are more balanced in terms of the number of interactions, contents, and transitions.

Scene	A	B	C	D (each scene)	E (each scene)	F
Number of texts (Rough no. of words)	~ 270	~ 1200	0	~ 20	~ 140	0
No. of images	9	32	41	14	1 ~ 8	90

No. of possible interactions	4	20	0	2	0	30
No. of scenes that it can transit to	3	3	1	13	1	1
Total scene area	12*12	12*12	36*36	12*12	12*12	12*12
Average total time people Spend (sec)	177	177	127.3	99.3	26.3	69

38
Virtual locomotion can be described as travel within virtual environments [33]

Interaction	**Walk to Trigger**	**Use Laser Pointer to Hover and Click**
Participant #1	The participant prefers this method because it feels more like being inside an actual exhibition.	The participant finds this method to be unexpected and feel disconnected.
Participant #2	The participant believes this method to be more interesting but admits that it takes too much effort after a while.	The participant feels that it is easier to point and shoot.
Participant #3	The participant believes this method is more intuitive.	The participant believes that this method is more suited to the VR environment.

Locomotion	Natural Walking	Sliding
Participant #1		This is the preferred method and what the participant mainly used. However, the participant suggested that the sliding velocity should be reduced.
Participant #2	This is the preferred method for the participant to move since it is easier to walk around and is more intuitive.	The participant mainly used sliding after becoming familiar with the hand controller, as it is easy to get lazy and not want to walk around anymore.
Participant #3	This is the preferred method for the participant to move around; however, the major problem is the limited activity space.	Even though the participant prefers natural walking, s/he moved by sliding more often.

Scene	A - Workspace	B - MapRoom	C/F - PhotoGallery	D - DailyActivity	E - Timeline	Whole Experience
Environment Design (including the "room" setting, lighting, materials of objects)	3	4.5	4	4.5	3	3.33
Interaction Design (how to trigger events, switch scenes, etc.)	3.5	3.5	3.5	3.5	2.5	4.33
Content Design (the content of the exhibition itself, what information is presented)	4	3	4	3.5	3	4.00

5 DESIGN GUIDELINE

5.1 Introduction

In City of Bits, William J. Mitchell describes the activity of designing a museum as "a task of relating wall or cabinet display space, with appropriate natural lighting, to a circulation system that efficiently conducts visitors through the collections" [30]. The activity of designing a VR-based virtual museum can be described in a similar format, even though the definitions of "walls or cabinet display space," "lighting," and "circulation system" are all different. From the perspective of an exhibition designer, who typically works with physical exhibition spaces, designing for VR implies that a completely different set of constraints must be faced, which would lead to a different set of design considerations and decisions. Meanwhile, from the perspective of a user interface design or website designer, they must adapt to the new dimensionality and find ways to transform the 2-D user interfaces with which they are familiar into something that better suits the 3-D environment.

5.1.1 Related Guidelines

Many design guidelines have been published by individual designers, technology companies, and research institutions to discuss the principles of designing experiences and applications for VR. Among them, some that I encountered while working on this thesis include Mike Agnes's master thesis "Visual Design Methods for Virtual Reality" [31], Intel's "Guideline for Immersive Virtual Reality Experience"[39] and Microsoft's "Mixed Reality Documentation for Design." [40] The documentation is written for HoloLens specifically; therefore, not everything could be applied to designing for VR. Moreover, Leap Motion has a "VR Design Guide,"[41] which joins user experience design principles and knowledge from ongoing VR development and user testing. In addition to written documents, various video tutorials have been published by individuals and organizations. A few worth mentioning include the "VR Interface Design Pre-Visualisation Methods" by Mike Alex[42], "Designing Screen Interfaces for VR" from Google i/o 2017, and "VR Design:

39
Intel Guidelines for Immersive Virtual Reality Experience: https://software.intel.com/en-us/articles/guidelines-for-immersive-virtual-reality-experiences

40
Microsoft Mixed Realiy Documentation for Design: https://docs.microsoft.com/en-us/windows/mixed-reality/design

41
VR Design Guide by Leap Motion: http://blog.leapmotion.com/vr-design-guide/

42
VR Interface Design Pre-Visualisation Methods: https://www.youtube.com/watch?v=id86HeV-Vb8

Transitioning from a 2D to 3D Design Paradigm" published by Samsung Developer Connection[43].

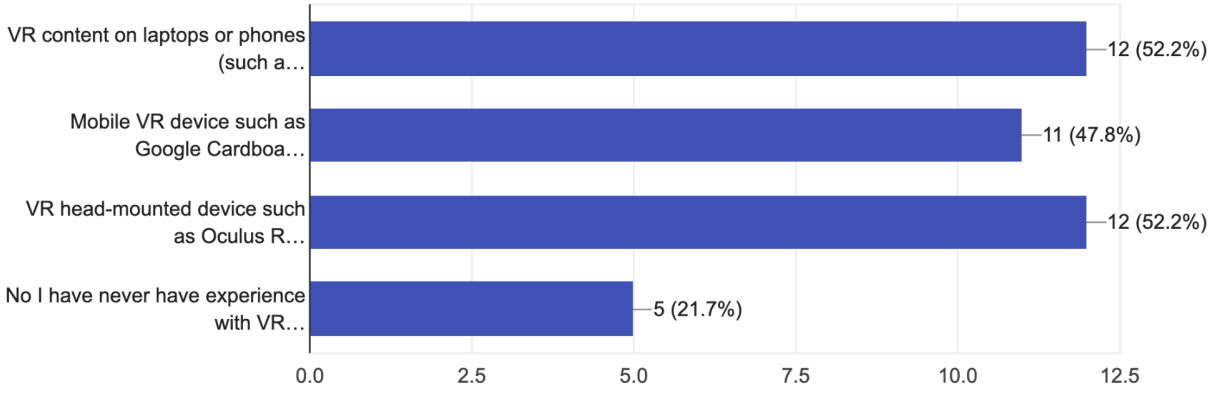
Most of the existing design guides are created for general purpose use without a specific type of VR application in mind, while the design guideline from this thesis focuses on the aspects that are relevant to virtual museums and virtual exhibitions.

43
Designing Screen Interfaces for VR (Google I/O '17): https://www.youtube.com/watch?v=ES9jArHRFHQ

5.2 Design Principles

5.2.1 Adaptive Design for VR

Results from the Questionnaire



5.2.2 Cybersickness

Cybersickness refers to motion sickness-like symptoms that people may develop while experiencing VR contents [32]. This could be caused by a mismatch between different sensory channels or by technical issues of rendering the virtual environment, such as a low frame rate, position track errors, lags, and flickers [32]. Certain design decisions can be made to reduce the occurrence of cybersickness. For example, Intel's "Guidelines for Immersive Virtual Reality Experiences" list the following examples for preventing cybersickness:

> "Respond faithfully to the user's movements at all times, preferably at or near typical human locomotion speeds."
>
> "Avoid having moving objects that take up a large portion of the user's field of view, to prevent feelings of self-motion."
>
> "In teleporting, provide adequate visual cues to retain bearings and preserve original orientation if possible."

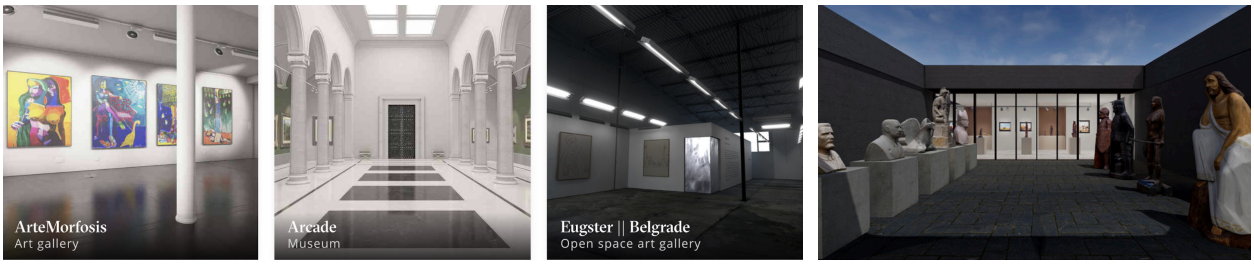
5.3 Design Factors

5.3.1 Environment (exhibition space)

One important feature of VR compared with 2-D user interfaces is the presence of its environment. When designing VR applications or experience, designers always struggle to balance its contents and its environment such that the environment design adds value to the contents rather than overpowering it.

When designing virtual museums in VR, one intuitive approach is to replicate the design of a physical museum or gallery space and position it inside a virtual environment. Such a method offers an advantage by placing the visitor in a familiar environment, therefore providing greater design affordance. In addition, architectural details provide a sense of scale that we understand subconsciously, which helps in making the experience more immersive.

Three development stages of a 360 Video Test App by Samsung Research, in which the design paradigm shifted from 2-D to 3-D (Source: VR Design: Transitioning from a 2D to 3D Design Paradigm at 34:48)



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Left Three - VR All Art (Source: https://vrallart.com/)
Right - "The Virtual Gallery of Art" published on SideQuest (Source: https://sidequestvr.com/app/667/1)

Alternative approaches include viewing the environment as part of the content to be displayed, such as contexts of the artwork's original environment or the artist's working environment. Examples include the Modigliani VR: The Ochre Atelier developed by Tate Modern[45] and Mona Lisa: Behind the Glass developed by the Louvre Museum[46]. Such designs typically require extra time to create and construct but could fully utilize the strengths of VR.

45
Modigliani VR: The Ochre Atelier: https://www.tate.org.uk/whats-on/tate-modern/exhibition/modigliani/modigliani-vr-ochre-atelier

Left: Modigliani VR: The Ochre Atelier. Courtesy of Preloaded. (Source: https://www.tate.org.uk/whats-on/tate-modern/exhibition/modigliani/modigliani-vr-ochre-atelier)

Right: Mona Lisa: Behind the Glass (Source: https://www.viveport.com/18d91af1-9fa5-4ec2-959b-4f8161064796 at 3:36)

Another approach is to view the environment as the backdrop and container of the exhibition and to pursue a minimal design rather than create a realistic gallery space. When viewing 2-D online collection designs, one could easily discern that they always have a neutral background—most often white—to showcase colors from the artworks' images to the maximum degree. In applying the same strategy to 3-D space, designers could utilize skyboxes of the same color and minimize their presence by making the environment light dimmer. Even though the environment could be minimal, designers should still consider adding in grounds and furniture nearby to lend users a sense that they have something upon which to stand.

46
Mona Lisa: Behind the Glass: https://www.viveport.com/18d91af1-9fa5-4ec2-959b-4f8161064796

Light, Color, and Texture

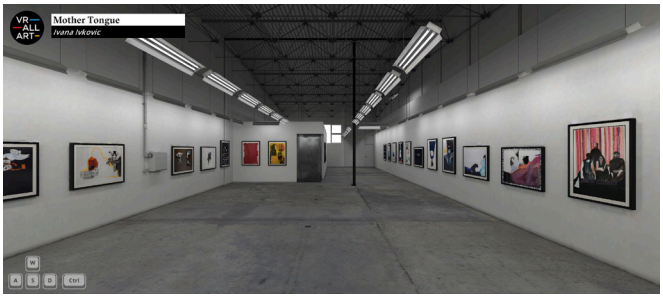
The lighting design for VR exhibitions could refer to similar methods when designing physical exhibitions inside museums. Without the need of worrying about potential damage caused by lighting to artworks, the lighting should be designed to provide the best illumination for the artworks to be readable. In addition, the lighting could be used as a device to influence visitors' movement inside the virtual space. For instance, in both the MFA Case Study and the Art of Memory case study, I constructed scenes that have spotlights lighting up only the central space, and even without a physical boundary, visitors tend to stay within the illuminated area. In addition, lighting could also be used as an interactive element

inside the VR space, moving around and being switched on and off for specific purposes.

The choice of colors and textures for both the environment and the objects within the VR space could be derived from the feeling that the design wishes to convey. For instance, in the Kermer Museum[47], metal and marble textures are used to lend the space a classic and epic feeling. Meanwhile, in the Mother Tongue VR Exhibition at Eugster || Belgrad by Ivana Ivkovic, the concrete floor and folded metal ceiling provide the virtual space an industrial and modern appearance[48].

47
The Kremer Collection: https://www.thekremercollection.com/the-kremer-museum/

48
Mother Tongue VR Exhibition at Eugster || Belgrad published on VR-ALL-ART: https://vrallart.com/vr-exhibitions/eg/ivana_ivkovic



Left: Kermer Museum (Source: The Kermer Museum at 00:32, https://www.thekremercollection.com/the-kremer-museum/)

Right: Mother Tongue VR Exhibition at Eugster || Belgrad published on VR-ALL-ART (Source: https://vrallart.com/vr-exhibitions/eg/ivana_ivkovic)

5.3.2 Soundscape

Physical museums, especially art museums, typically do not implement environment soundscapes to keep the experience free of interruptions. Personal devices are commonly used when there is a need to discuss a specific object or exhibitions in audio format. In VR, since the visiting experience becomes primarily private, a soundscape could be designed and implemented more easily to enhance the experience. One VR experience worth mentioning for excellent soundscape design is the Notes on Blindness[49], which is based on John Hull's audio diary after he became blind. It uses binaural sound to convey the experience of John Hull with minimal visual hints inside the VR space.

49
Notes on Blindness: https://www.with.in/watch/notes-on-blindness

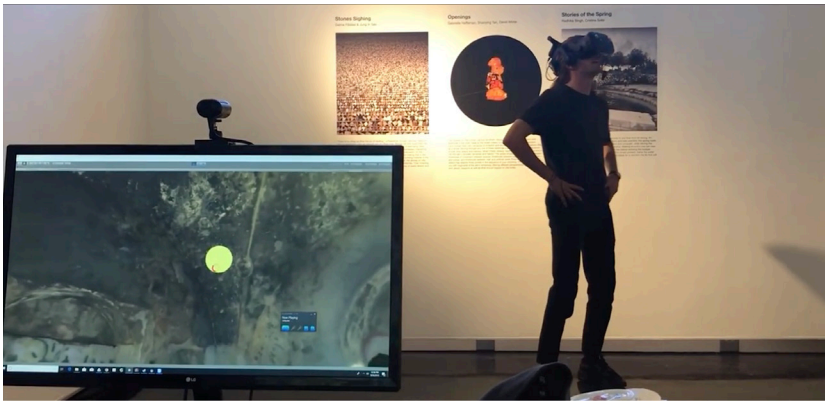
5.3.3 Interaction

Human-computer interactions that could be applied in a VR experience are extremely diverse given the set-up of the system. With head positions and orientations tracked, VR devices constantly collect corresponding data, which is used to trigger different types of events. In addition, more advanced VR headsets commonly feature hand controllers, which provide additional means to interact.

Gazed-Based Interaction

Gaze-based interaction could be applied to any three degree-of-freedom (DoF) systems[50], since it requires rotational information from the head (eyes), therefore making it the most inclusive. It shoots a raycast from the users' head (eyes) position to the direction they are facing and detects whether such a line intersects with any objects. With gaze-based interaction, the interactive UI is always located at the center of the viewport when it is triggered, which is generally a good practice but also has its limitations.

Degree of Freedoms: https://developers.google.com/vr/discover/degrees-of-freedom



Digital Archeology, Virtual Narratives: The Case of Lifta and its gaze-based interface (Source: http://virtualxdesign.mit.edu/digital-archeology-virtual-narratives)

Collision Trigger

Another method is collision triggering, in which events are triggered when objects collide with specific parts of the user's avatar. This method is commonly used to interact with objects in the scene, including grabbing and throwing them. However, this requires the objects to be within reachable areas around the user, which could create extra work.

Hand-based Laser Pointer

A laser pointer uses a similar mechanism, but the raycast comes from the hand controllers rather than the headset, therefore having extra requirements regarding the type of VR device. Compared with collision triggers and gaze-based pointers, laser pointers from hand controllers generally offer more freedom.

Locomotion

Virtual locomotion can be described as travel within virtual environments [33]. The most common locomotion methods include

natural walking and teleportation. Other options include redirected walking, which is designed to achieve a natural walking experience within a limited space. Locomotion can also be achieved with a trackpad on hand controllers or reply to a variety of customized devices, such as a step pad or bicycle, among others. In addition, it could be transformed into more playful ways, such as flipping and flying gesture recognition.

In virtual museums or exhibitions in VR, natural walking appears to be the most intuitive way for visitors to move around, even though it requires a large area of activity space. When designing for a small activity area or a seated experience, teleporting and sliding with controllers are the alternatives.

Left: Legible City by Jeffery Shaw and Dirk Groeneveld (Source: https://www.jeffreyshawcompendium.com/portfolio/legible-city/)

Voice Command

Speech is considered the most natural way to communicate [34], which can be achieved by speech recognition and voice command. When applied in VR, these methods allow users to become further immersed in the 3-D world.[51] Speech recognition is defined by Weinschenk and Barker as "the technologies that enable computers or other electronic systems to identify the sound of a human voice, separate that sound from noise in the environment, and accept the messages from the voice as input for controlling the system" [35].

51
Virtual Reality Needs Voice Control:
https://blog.globalwebindex.com/chart-of-the-day/virtual-reality-needs-voice-control/

In museum environments, conversations occur not only between

visitors but also between guides and visitors. A voice command system that simulates the experience of speaking with a museum guide could be implemented as part of the VR exhibition. Such a voice user interface (VUI) allows users to learn more about artworks and an exhibition in a more intuitive form.

Gesture Recognition

Even though most popular headsets, such as the Oculus Rift/ Quest and HTC Vive, use controllers as the primary method of interaction, many explorations have been made in the field of hand gesture recognition as an alternative interaction method. Previously, researchers would hack their own customized set-up, which includes embedding Leap Motion onto the VR headset to enable gesture detection. The potential to improve the experience design for VR is recognized: in Oculus's new release, hand tracking is presented as a developer preview feature.[52]

52
Unity Developer - Hand Tracking: https://developer.oculus.com/documentation/unity/unity-handtracking/?locale=en_US

5.3.4 Information Architecture

Considering the evolution of museums, one can observe that there is a decreasing density in terms of the information displayed in a given amount of spatial area. During the "Cabinet of Curiosity" period, display rooms were typically filled with objects and labels surrounding the objects. Modern art museums, however, are designed to be more spread out. With ample white space in between artworks, this allows visitors the room to breathe and reflect. The same consideration should be taken when designing virtual exhibitions. In addition, information should also be arranged in a way that is easy for visitors to digest. More specifically, introductory information of the exhibition should be placed in the entrance of the exhibition, while detailed descriptions of each artworks placed in the second layer of the information hierarchy, giving visitors the choice of not interacting with them.

5.3.5 UI Elements

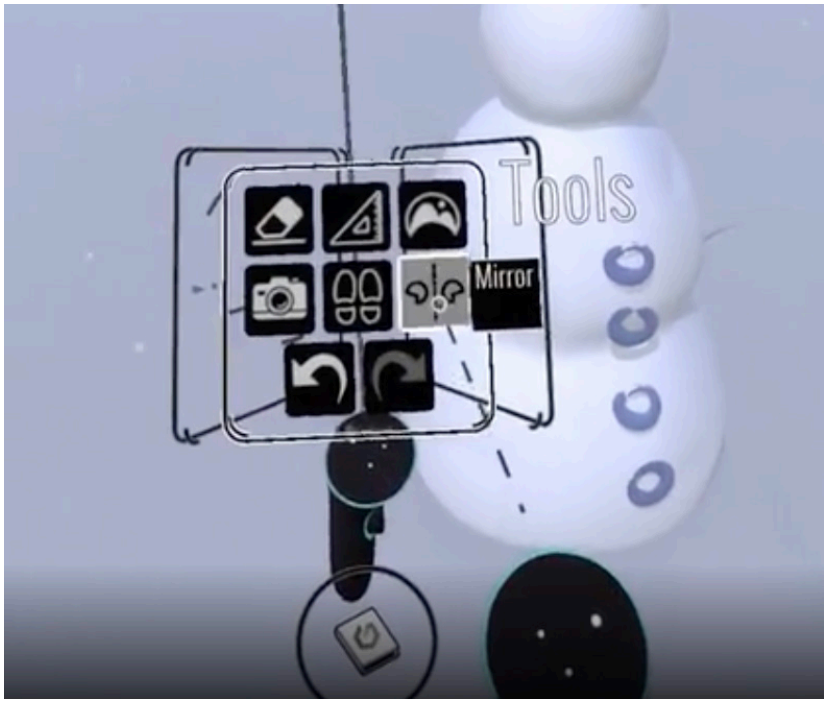
One theory mentioned during the "Designing Screen Interfaces for VR" presentation at the Google I/O conference in 2017 is that human beings are so used to receiving information on projected 2-D screens, as this is what we experience each moment in our real lives, and that is how human eyes work. When designing a user interface for VR, we are essentially designing a 2D screen inside the virtual environment. On the other hand, given the nature of VR, designers

have been searching for ways to make the 2-D user interface more 3-D, some of which have been successful while others not. In this section, several of the most common UI elements and their designs are discussed.

Menus

Menus in VR generally share a similar appearance as menus in a 2-D interface. However, there are many ways to position such a menu in a 3-D environment. One common type is a hand menu, which means that the menu appears in the same location as one of the user's hand anchors and follows that hand anchor around. Such an approach provides the user maximal control over where the menu appears. This is generally utilized within a two-controller system so that the user could use the other hand to interact with the menu. Similar to the hand menu, another approach is to place the menu around the user and make it move with the user; by doing this, the menu always remains within a reachable area, even though it is not attached to any specific body part.

In addition to the hand menu, the other common menu system design is for it to be triggered by certain keys on the controller. Once triggered, the menu is displayed at fixed locations within the user's viewport. The display of such a menu is independent from the users'



Left: 3-D Hand Menu from Google Tilt Brush (Source: https://www.tiltbrush.com/ "Intuitive Interface" at 00:28)

movement within the virtual space but covers a large portion of the user's viewport once triggered.

Another type of menu may be displayed at a fixed location inside the 3D environment; however, such a positioning method has many disadvantages. For instance, once the user has moved around inside the virtual space, it would be difficult to reach or find the menu again. This would be sensible if the menu is associated with the specifical location or object at which it is placed; however, it would make little sense if it were a universal menu for entering or quitting the experience.

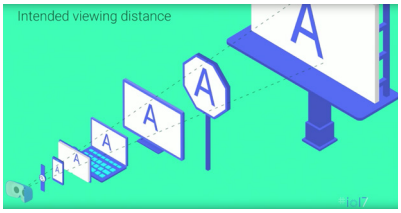
Text Box and Tooltip

Text panels are one of the most essential elements of an exhibition design and have been part of the development of museums over centuries. They are composed of labels that are located next to each artifact to offer an explanation of them, in addition to larger panels that describe the entire exhibition. Similarly, with physical exhibition design, readability is crucial when designing text boxes for VR exhibition.

Designers at Google created a unit named dmm (distance independent millimeter) to describe interface sizes in VR. 1 dmm is equal to 1 millimeter at a meter away. The image above describes good practices of determining text size and hit size in dmm.[53]

While designing the text boxes, one should also consider whether to include a background color, which could help to improve the readability of the text based on its background environment. In addition, instead of placing the text box in a fixed position statics,

53
Designing Screen Interfaces for VR (Google I/O '17): https://www.youtube.com/watch?v=ES-9jArHRFHQ



Right: Recommended text sizes and hit sizes (Source: Designing Screen Interfaces for VR (Google I/O '17) at 20:27)

Left: Concept illustration of the angular size (Source: Designing Screen Interfaces for VR (Google I/O '17) at 4:57)

one should consider making it dynamic by always facing the player or following the player, thus increasing readability.

Keyboard

It is common to see attempts to reconstruct physical keyboards in virtual space in either 2D or 3D, and they allow users to interact with them using a laser pointer, which is much more difficult to control than a physical keyboard. However, combining such a design with hand tracking could be a promising direction to explore.

Slider, Toggle, Button

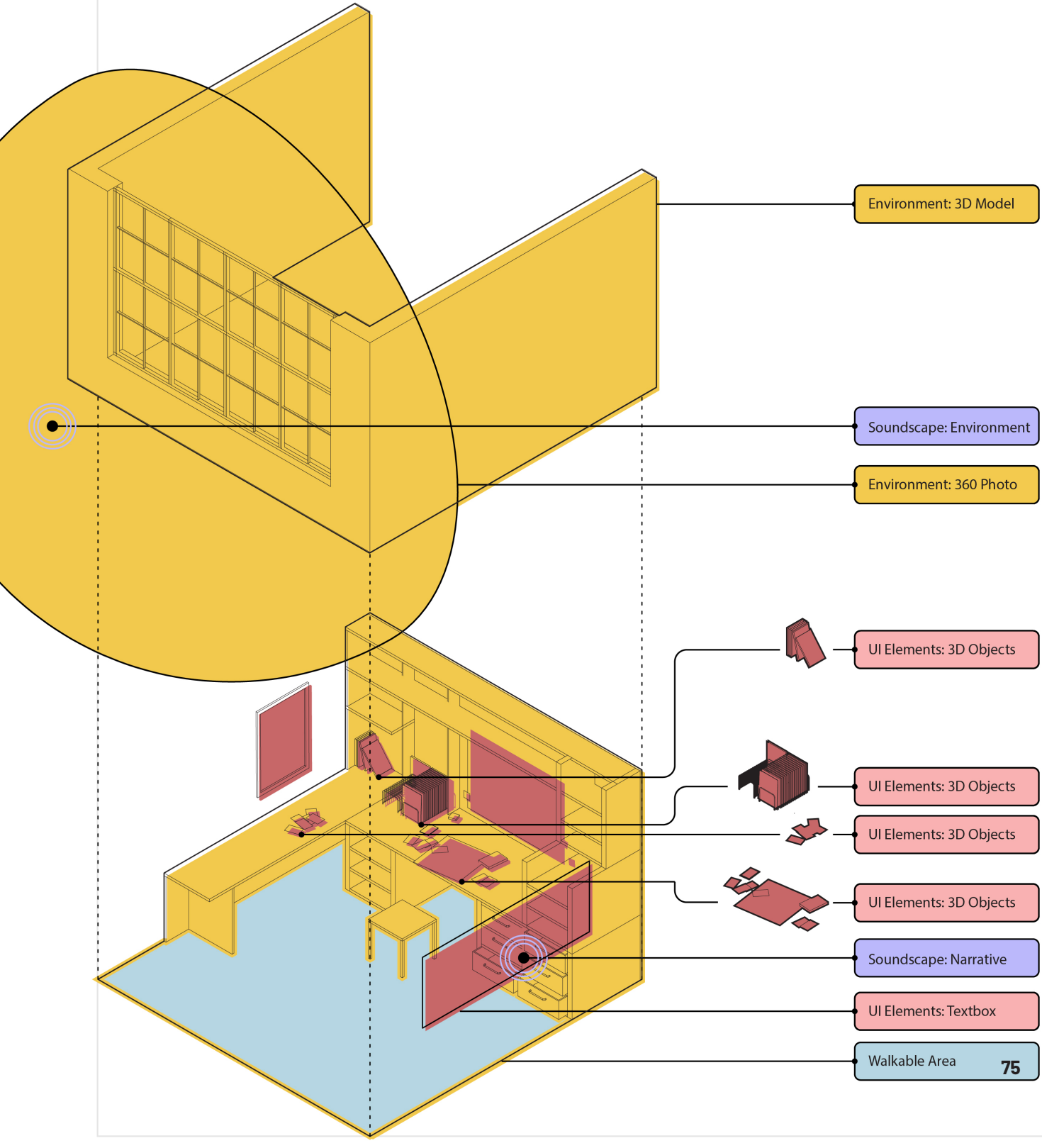
While many attempts have been made for those elements to be more 3D in appearance, many VR applications still replicate the design of those elements from 2-D user interfaces. Since the design of those elements is derived from physical objects or interfaces in 3D, replicating those 3-D objects is another direction worth pursuing.

5.4 Design Templates

From the two case studies, six templates are designed and developed throughout the process, as means to showcase different types of information.

5.4.1 Template A - Environment

This template design is a good starting point for exhibitions that contains different types of artworks, such as an exhibition for some artists, historical figure, or historical events, where the materials to be presented at the exhibition includes long paragraphs of texts, images and paintings of various scales, and multimedia contents such as video, audio and so on. The environment could also be designed to showcase additional information of the artists or the artworks.

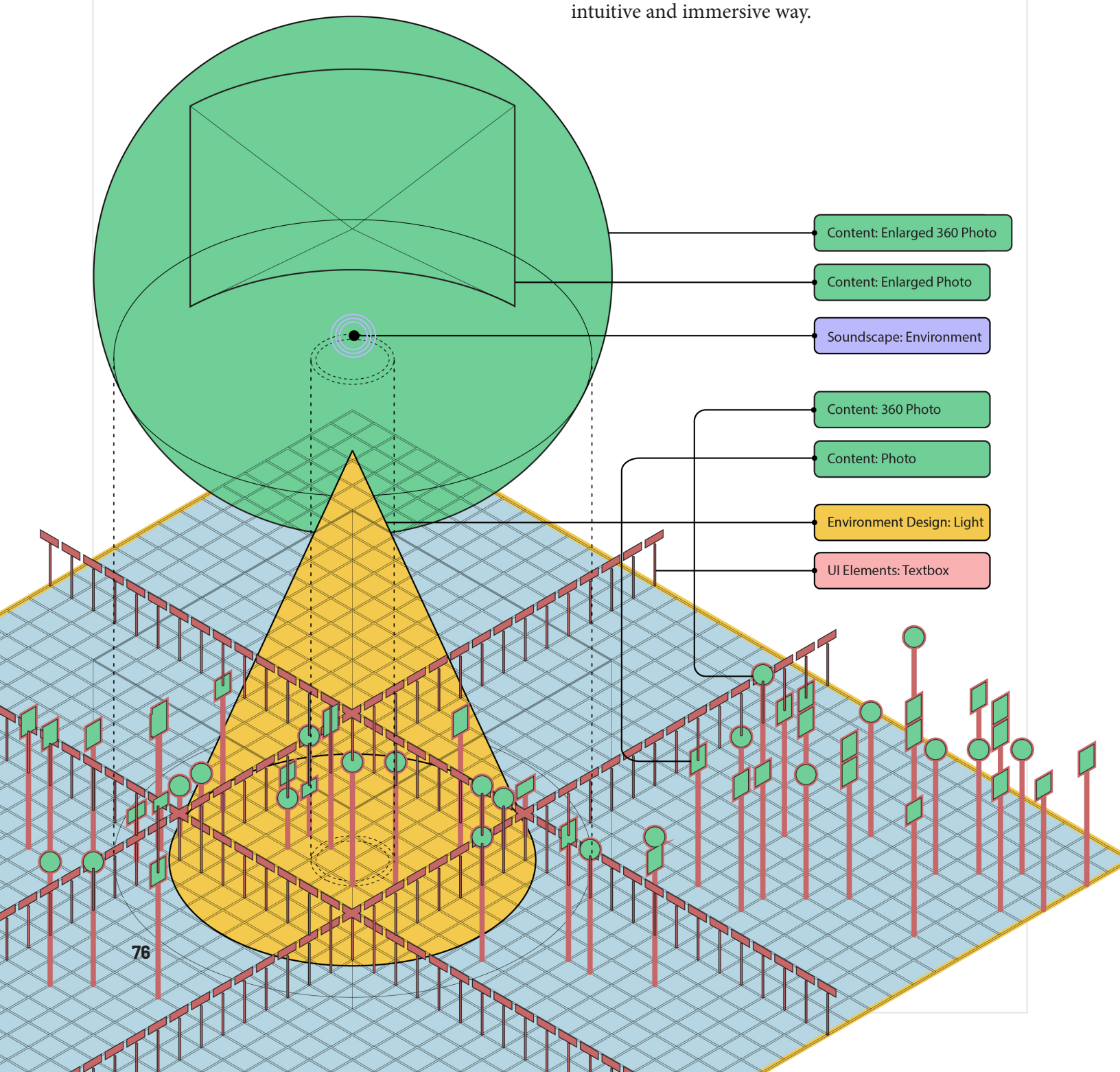


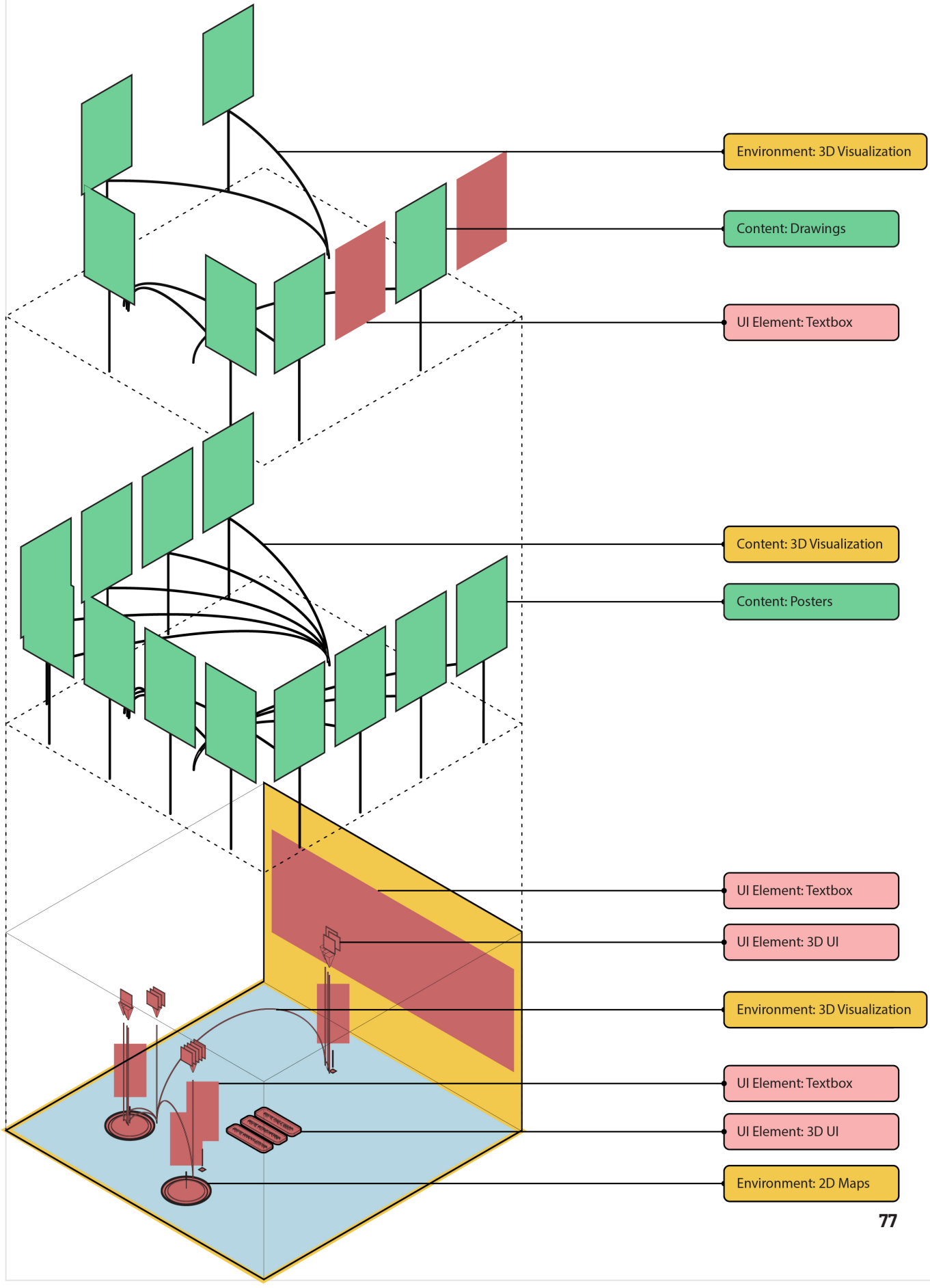
5.4.2 Template B - Inventory Space

The inventory space template can be seen as a dataset of the museum's collection being visualized in a 3D format. Artworks are represented through thumbnails, which could be either 2D or 3D.

5.4.3 Template C - Map

Geospatial information is also something important to link the different artifacts from the exhibition. However, this information is usually showcased in the text panels, or interactive screens next to the actual exhibition contents. VR, however, allows us to actually put objects inside a larger, and more interactive map, therefore displaying geospatial relationships between different artworks in a more intuitive and immersive way.




Environment: 3D Visualization
Content: Drawings
UI Element: Textbox
Content: 3D Visualization
Content: Posters
UI Element: Textbox
UI Element: 3D UI
Environment: 3D Visualization
UI Element: Textbox
UI Element: 3D UI
Environment: 2D Maps

6 CONCLUSION AND FUTURE WORKS

6.1 Conclusion

The thesis indicates that, accompanied by the shifting identities of museums throughout history, museum buildings and museum collections have been in a dynamic relationship. As the tension between museums' new goal of serving a wider audience and their long-term mission of being responsible for their collections increases, VR has proven to be a good medium for museums to extend their virtual identity and provide experience beyond their physical buildings.

Compared with traditional physical exhibitions, virtual exhibitions in VR offer many advantages: they have much higher capacity to accommodate the accumulating collections, they break the physical boundaries to create connection between different museums, and they have the ability to showcase spatial contexts in a immersive manner with the additional time factors and multimodal interactions. In addition, they could provide a customized experience based on the visitors' identity and provide visitors the space to curate their own exhibitions, thereby aligning with the shifting roles of visitors and curators. Last, they provide convenient methods for evaluating visitors' experience in quantitative ways, which are lacking in traditional exhibitions.

After considering a wide range of existing projects and design methods as well as testing with two case studies, this thesis concludes that a modularized design system and an object-oriented approach could help modern museums to construct such exhibitions with capacity, connectivity, immersiveness, and flexibility in an efficient manner.

6.2 Limitations and Future Works

This thesis only looks at the construction of virtual museums and virtual exhibitions from a design perspective, while other factors

such as computing power, the public's accessibility to VR devices, and setup of the working pipeline in between the back-end database and the visualizations in VR is not discussed.

This thesis proposed a modularized and object-oriented design approach to create virtual exhibitions, and proposed three templates that can be referred to based on the field survey, previous case studies and user experiments. The design of these templates, however, still need more usability tests to be validated. Currently the three templates are focusing on the scenarios when a collection of related artifacts is displayed in the same scene, while in the future templates that are designated to showcase certain aspects of individual artifacts, such as its evolution over time, its content, as well as its material and technique, could be generated.

The design guideline delivered as part of the thesis does cover most aspects of the design of a virtual exhibition. At the current stage, however, it relies mostly on theories and principles summarized from literature of different fields. More precedents could be added to be viewed as references and inspirations, which are not limited to exhibition contents but a wider range of VR applications. UI components could be constructed for each UI element and presented in a more visually-oriented format. Those UI components as well as the templates could be constructed as Unity Prefabs, which would allow a wider group of users to try them and collect feedback.

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