Effect on User Experience in a Virtual Heritage Environment Comparison between AVIE360 and HMD

Woon Him WONG

A Thesis in the Field of Interactive Digital Media
for the Degree of Master of Science in Interactive Digital Media

Supervisor: Dr. Néill O'Dwyer

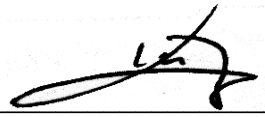
Trinity College Dublin
May 2019

Declaration

I have read and I understand the plagiarism provisions in the General Regulations of the University Calendar for the current year, found at: http://www.tcd.ie/calendar

I have also completed the Online Tutorial on avoiding plagiarism 'Ready, Steady, Write', located at http://tcd-ie.libguides.com/plagiarism/readysteadywrite

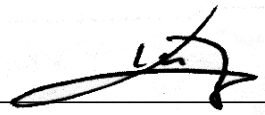
I declare that the work described in this research Paper is, except where otherwise stated, entirely my own work and has not been submitted as an exercise for a degree at this or any other university.

Signed: 

Woon Him Wong 10/05/2019

Permission to lend and/or copy

I agree that Trinity College Library may lend or copy this research Paper upon request.

Signed: 

Woon Him Wong 10/05/2019

Abstract

In recent years, various types of virtual environments have been culturally embedded and developed as immersive interactive Virtual Heritage Environments (VHE). Rapid advances in digital media and Virtual Reality technologies offer new possibilities for virtual heritage. The research scope of this dissertation will be focused on offline tangible cultural heritage sites. Tangible cultural heritage refers to sites, monuments, buildings with historical, aesthetic, archaeological, scientific or anthropological value, whereas virtual heritage refers to instances of these cultural heritages within Virtual Reality (VR) environments. More precisely, this paper concentrates on 'offline' types of virtual heritage, which means there are no online, networked multi-users in the virtual environment, because this is the major representation type of virtual heritage on the current market. VHEs not only potentially help lessen the impact of tourist erosion thereby protecting overrun/damaged tangible heritage, but they also provide a realistic 3D virtually reconstructed historical experience for visitors, travelers and even residents.

These kinds of virtual heritage applications can be brought to different VR environment systems, i.e. portable devices (e.g. Head-Mounted Displays) as well as complex, large devices (e.g. CAVEs, Tiled Projection Displays). Most of these technologies aim to support an immersive environment for user. Many researcher studies have focused on comparing the performance and effectiveness between using the CAVE and HMD formats, and the 'process' or the 'product'; but, less consider the 'users. Therefore, this paper examines how different system configurations and user engagement paradigms influence users' experiences in virtual heritage (e.g. the amount of audience members, the viewing conditions, and the modes of interaction).

This paper focuses on comparing the Advanced Visualization and Interaction Environment (AVIE) and Head Mounted Display (HMD). While most people are already familiar with HMD experiences, the AVIE is a 360-degree virtual reality installation environment, which was invented in 2007, and has pioneered a new form of virtual

heritage experience in recent years. Both systems have unique benefits and differences, and they are co-existing in the virtual heritage market at the same time.

In terms of user experience, it is hard to predict. Thus, by a thematic analysis, this thesis evaluates and describes how differences between these 2 types of VR systems impact on users' visual conditions, behavioral interactions, feelings, sense of immersion, and sense of presence/co-presence.

Finally, this dissertation investigates the positive and negative characteristics of each system and the differences in user experience through qualitative approach. I have conducted a comparative study on using AVIE360 and HMD to explore tangible virtual heritage applications. This paper will not just analyze the impacts on user experience from a technological perspective, but also from museological, psychological and sociological aspects. The differences in user experience by viewing conditions, and modes of interactions is discussed in detail via themes and features emerging from the analysis. These results aim to guide future curators, museum managers and system-builders to make an informed decision when selecting an appropriate system display for experiencing Virtual Heritage in different conditions.

Acknowledgements

It is a genuine pleasure to express my thanks and gratitude to my supervisor, Dr. Néill O'Dwyer. As this is my very first academic research paper, he is the one who guided me thought how to reduce the scope, turned my research interest area into a specific research topic, helped me to develop the writing structure and apply appropriate methodologies. He consistently allowed this paper to be my own work but steered me in the right direction whenever he though I needed it.

I would also like to acknowledge Professor Jeffrey Shaw, spending his time to conduct an online interview and he patiently and detailly answered all of my questions related to the AVIE360 and virtual heritage in VR systems.

Thanks my family for providing me with constant support and encouragement throughout the process of my master study. This attainment would not have been made without them.

Finally, I must express my very profound gratitude to Dubois coffee for providing me with constant support throughout the process of my writing. I would also like to thank my best friend Yim Mei Kwok for wise counsel and sympathetic ears.

Woon Him Wong

Table of Contents

Chapter 1.

Introduction

Tangible cultural heritage contributes to our modern society, it is a process of memory and oblivion that provides us with physical evidences to build our connection to past cultures. Therefore, they are worthy of being preserved for future generations; yet, the statistical report from UNESCO (Armstrong, 2017), revealed the extent to which natural World Heritage sites are in danger due to common threats like invasive/non-native species, climate change and the effects of tourism and recreation.

VR technology continues to evolve, undoubtedly, it will become more prevalent throughout society, in general, and the tourism sector in particular (Guttentag, 2010). Numerous VR's applications for the tourism and cultural sector have been developed and its implications for the sector are significant. Also, the increasing development techniques and devices has effectively improved the efficacy and usability of virtual heritage (VH) and the use of advanced systems for implementation of cultural heritage.

Head Mounted Display (HMD) and 360-degree Advanced Visualization and Interaction Environment System (AVIE360)

Nowadays, HMD is the most familiar and major VR system or device that is widely used by general public. HMD is an effective solution for experiencing virtual heritage without any time and geographical limitation. Meanwhile, there is another type of system, AVIE360, which is a shared environment with a tiled display panoramically surrounding the user/visitor. It has started to be used in permanent virtual heritage installations in museums or public spaces (Shaw, 2019).

AVIE360 is a real-time 360-degree omnistereo projection with surround audio and marker-less motion tracking that provides a highly immersive and interactive environment for more than 20 (usually around 30) users at the same time.

The question arises as to the nature of the user experience for a visitor/tourist when experiencing virtual heritage in a panoramic projection environment system compared to a head mounted display system. There are many reasons that a virtual heritage visitor or a developer may prefer one system over the other. Therefore, it is interesting to discover in detail how the user experience differs between AVIE360 and HMDs when users are exploring virtual heritage applications.

The importance of desirability in user experience

The four main elements of user experience are value, usability, adoptability and desirability. Guo states that many products are both easy to use and valuable, but they end up failing in the marketplace because of their lack of desirability (Guo, 2012).

Desirability relates to emotional appeal (Guo, 2012), which is determined by the experience and fun of engaging with it.

Therefore, this paper will not only analyze the usability of virtual heritage application among these 2 systems, but also the enjoyment and the extent of engagement.

This study explores how these system configurations and user engagement paradigms cause difference impact on user immersion, sense of presences, engagement, viewing conditions and mode of interaction. After analyzing the pros and cons, of their own features, this study will evaluate these two types of systems for their suitability depending on user desirability and certain circumstance in order to establish a guide when selecting an appropriate immersive display system for different virtual heritage applications.

1.1 Methodology

Qualitative research methods are adopted in this research.

Firstly, Comparative studies are used to evaluate the major technical differences between HMD and AVIE360, from the user perspective. Their systems' technical conditions, space, volume, visual conditions etc. are analyzed to examine how these aspects influence user experience and create unique experience through the design features of the system itself.

Then, two similar types of published virtual heritage applications are selected as case studies. They are *"Pure Land: Inside the Mogao Grottoes at Dunhuang" in AVIE360* and *"Nefertiti: Journey to Eternity" in HMD with HTC Vive*. By analyzing the application design features differences and evaluate how the content design affected by the system itself in order to prove what extent to the uniqueness of the user experience qualities on both HMD and AVIE360.

Secondly, a qualitative interview with, expert, Professor Jeffrey Shaw is conducted. He is a professional new media artist as well as the creator of AVIE360. The interview helps us to understand more about the design concept and principles of the AVIE360 system and to analyze the specific features of these two environmental systems, based on his professional knowledge on museology and VR technologies, and his experiences on developing in virtual heritage applications for different VR environment system.

Combining the above methods and second-hand literature references, including psychological, and sociological theories, and existing technical comparative research results on user experiences of VR systems, helps this paper prove that both AVIE360 and HMDs have their own specified qualities and features when presenting virtual heritage experiences, by analyzing various aspects of their pros and cons.

1.2 Chapters Overview

Chapter 2 provides an overview of the field and summarizes the existing works and literatures relating to comparative studies on VR systems, and research studies of user experience in VR and VH. By reviewing this literature, discussion of their shortcomings, limitations and benefits are provided.

Chapter 3 and 4 are case studies.

Chapter 3 is a case study of AVIE360 with the virtual heritage application which is called *"Pure Land: Inside the Mogao Grottoes at Dunhuang"* and **Chapter 4** is a case study of the HMD with a different virtual heritage application, called *"Nefertiti: Journey to Eternity"*. It analyzes the features of the corresponding system first, then take the application case study to show how those features of the VR system impact on the virtual heritage application content design and its user experience.

Chapter 5 gathers the analytical results from the case studies, comparing the differences between these two systems and applications. It discusses the pros and cons on each side and suggests what kinds of possible future solutions and techniques can overcome the existing shortcomes.

The final chapter (**Chapter 6**) draws a conclusion on how AVIE360 and HMD differ from each other when being used to explore virtual heritage applications. It evaluates the suitability and future development possibili**ti**es in virtual heritage among AVIE360 and HMD. In addition, it suggests any further related research that can be made in regard to the limitations of this paper.

Chapter 2.

Existing Knowledge / Literature Review / Related Works

Overview of field and Existing Issues

3D visualization and restoration in archaeology and cultural heritage has a long history of development since 1980s (Arnold et al.,1989; Reilly and Shennan, 1989). Looking through the second decade of 21st century, many virtual heritage projects are still scattered. Laia Pujol Tost and Erik Malcolm Champion criticized the VR projects on cultural heritage sites for being mostly based on single-user, limited interaction, and for the confusion arising from a minimum of navigation cues, or far too much overlapping information. (Tost and Economou 2007). This criticism may be overthrown, by AVIE360, which is designed for group participation and it aims to offer an immersive and interactive virtual environment for visitors.

2.1. Virtual Reality (VR)

The general approved definition for VR is the use of a computer-generated 3D environment, which provides navigation and interaction for users, and brings on real-time simulation of one or more of the five human senses (Burdea and Coiffet, 2003; Guttentag, 2010).

According to most of the research papers (William and Hobson, 1995; Cruz-Neira, Kenyon & Hart, 1992), to be specific, the three major characteristics of VR are: 1) Visualization, where the user is able to look around, the most common way is using HMD; 2) Immersion, a suspension of belief and physical representation of objects; 3) Interactivity, a degree of control during experience, usually achieved with trackers, sensors and different input devices.

Therefore, the comparative analysis in this paper will be based on these key elements, the visual condition, level of immersion and the range of interactivity.

2.2. Shared projection immersive environment/system

Although there are lot of extensive scholarly studies on projection display technology and large-screen display systems (i.e. reality theatres), almost all publications describe the development of the technology itself instead of evaluating the effect of the technology on the participant's perception/user experience.(McGinity et al., 2007; Cruz-Neira, 1993; Kulik et al., 2011 and Dominjon et al., 2005)

2.3. Different type of VR display systems

Bend Kiang Tan and Hafizur Rahaman explain the method of developing and disseminating virtual heritage in VR nowadays (Tan and Rahaman, 2009). *Figure 1* below shows the present types of VR display systems using in virtual heritage. They are Immersive Projection, AVIE, CAVE and HMD.

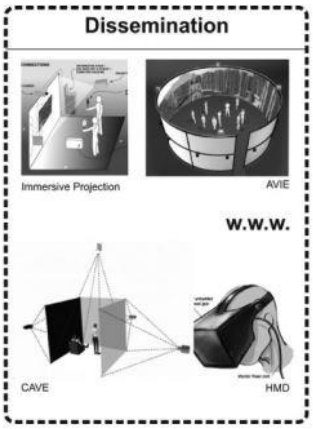


Figure 1

The development of different VR devices, systems and technologies are more advanced nowadays. There are lots of interesting installation-based virtual heritage sites like iCinema from UNSW, and large planetarium displays such as the Hellenic World, the curved wall of the Earth Theatre at the Carnegie Mellon Museum of Natural History.

Yet, according Erik's research, he studied the history of cultural heritage in Virtual Environments, he stated that virtual heritage projects that rely on the traditional virtual reality technology like HMD and CAVE are few and far between (Champion, 2014). Nevertheless, the reason why HMD and CAVE are less adopted in virtual heritage are missing. Assuming this is because of the technological constraints on the traditional

virtual reality, a lot of new and advanced technologies have been improved the HMD for the recent years. Therefore, it is worthy to compare how AVIE360 (new type of large panoramic displays) and HMD effect the user experience in the field of virtual heritage.

The user experience of a virtual exhibition is influenced by the technology used, thus the consideration of using which display system is important. Marcello Carrozzino and Massimo Bergamasco well explained how the level of immersion is linked to the display systems (Carrozzino and Bergamasco, 2010). Especially, external display systems, for instance, Power Wall and CAVE, (Cruz-Neira et al, 1992; Lee et al, 2010) proved they provide the highest level of immersion.

2.4. Comparative studies between different VR system displays

However, the current comparative studies of different VR display systems are limited with HMD, Desktop PC and CAVE only. In particular, HMD versus CAVE is the most popular comparison. For example, Daniel R. Mestre compared the differences between CAVE and HMD in an experimental approach and summarized into three factors on interacting with objects, acted affordances and clinical feedback (Mestre, 2017). Athanasios Gaitatzes, Dimitrios Christopoulos and Maria Roussou generally compares the pros and cons between the interactive virtual environments (CAVE and HMD) and discuss the issues involved in developing immersive interactive virtual archaeology applications for public on these display systems (Gaitatzes et al., 2001).

A few researches have done the user experience studies by comparing VR display systems, but they are all based on HMD and CAVE. Also, none of the user experience comparative studies are analyzed when these display systems are used for experiencing virtual heritage.

For example, Katy Tcha-Tokey and others used a unified questionnaire to measure, analyze and compare the user experience in CAVE and HMD (Tcha-Tokey et al., 2017). The results show that CAVE induced a greater user experience than the HMD with significant difference in presence, engagement, flow, skill, judgement and experience consequence, but no significant difference in immersion, usability, emotion and technology adoption between them. They only based results on questionnaire feedback from 21 participants who experienced in the same edutainment virtual application among

HMD and CAVE. The questionnaire result was not validated with any further theorical analysis. On the other hand, (Philpot et al., 2017) compared the user experience differences between HMD and CAVE too, but it focuses on the viewing conditions when watching a panoramic video. In this paper, it used a thematic analysis to do a comprehensive comparison. However, the results are categorized according to the feedback quotes from users, which made the conclusion not objective enough based on 'some' of the users' comments.

Limitation Summary

After reading through the existing literatures, there is no study or research that tries to compare HMD with the new type of SIDs, like AVIE360, so far. There is not much existing researches to analyze the user experience differences between HMD and shared immersive environments (besides CAVE) when using them as a display interface system in Virtual Heritage applications.

Comparing AVIE360 with CAVE, their design features and some technologies are very distinct. Moreover, in terms of virtual heritage, museums and cultural heritage centres may be in a better position to make use of advanced virtual reality technologies and contribute to a broad-based public acceptance of technology as a tool for the study and presentation of the past. Consequently, this paper is going to analyze the most up-to-date technologies used by AVIE360 and HMD to do a comparison and contrast in order to renew the knowledge of the existing research field.

Chapter 3.

Case Study 1 – "Pure Land: Inside the Mogao Grottoes at Dunhuang" in AVIE360

3.1. Project Background

Pure Land: Inside the Mogao Grottoes at Dunhuang is a new exemplary heritage application built by the Applied Laboratory of Interactive Visualization and Embodiment (ALiVE), which is an interdisciplinary research initiative of the School of Creative Media at the City University of Hong Kong in 2012 (Galeazzi, 2012).

Mogao Grottoes in Dunhuang is a quintessential cultural heritage of hundreds of Buddhist grotto temples, it is also known as 'the Caves of the Thousand Buddhas' which is originally located in north-western China. It reveals trade between China, western asia and India over 1000 years (from second century BC to 14th century AD).

Pure Land specifically brings the story into life as a single composition on the north wall in Cave number 220, which is named as '*Bhaisajyaguru's Eastern Paradise*'.

Due to heritage preservation, most grottos in Dunhuang Mogao are not accessible to the public. However, by using virtual reality technologies and virtualization, it allows people to experience the caves. Visitors are immersed in a large shared 360-degree panoramic projection theatre (AVIE360) with an dynamic, simulated experience of being inside a cave temple and seeing its magnificent Buddhist wall paintings at 1:1 scale.

The objects and figures in these wall paintings are dramatized by means of spectacular interactive 3D animations and digital effects that reveal their beauty and

underlying narratives. It is a milestone in sustainable preservation and new method of cultural hertiage interpretation for museums.

3.2. Generation of the Presentation

3.2.1. Technical Description of the AVIE360

The VR system of Pure Land was developed based on UNSW iCinema Research Centre's signature 360-degree stereoscopic interactive visualization environment, which is AVIE. Its system is very important to providing an environment which has the ability to perform practical experiences with multi-user interactive, immersive and narrative system when showing the virtual Dunhuang Mogao Caves as part of a public exhibition or a museum.

3.2.2. Features of the AVIE360 System Design

Screen Design

In order to provide a sense of immersion for a large group of visitors, a cylindrical screen design was adopted as it lends to the projection of omnistereo images.

The AVIE360 screen is a cylindrical projection screen of four metres in height by ten metres in diameter. According to the specification that stated by the Laboratory for Experimental Museology ("Systems – EMPLUS," n.d.), its effective resolution of the screen is 22,000 pixels x 1750 pixels.

With the aim of creating a seamless, realistic image across the entity of the cylinder screen surface, two techniques are adopted, they are *distortion mesh* and *blend texture*.

A unique mesh is required for each projector in order to map the desired imagery on to a suitably shaped mesh, then modulate the image with a suitable texture, which is blend

texture. According to Paul Bourke, the blend textures are generated using a simple model that defines the start and end points of each blend area with a gamma correction and power function (Bourke, 2004).

Image Generation

On the other hand, stereoscopy is a powerful element of enhancing immersion. Although most of the traditional stereo projection demands that a user's position and its orientation accurately match the position and orientation from which the imagery was rendered or captured. Practically, this is achieved by tracking the user's head position and orientation so as to render images in real time for an accurate view from the user's perspective. In AVIE360, Matthew McGinity and others mentioned this conventional rendering method precludes construction of a multiuser environment where people are free to move and look wherever they choose, it is not possible to produce correct images for everyone and satisfy the group users (McGinity et al., 2007)

The team adopted a method known as *omnistereo*, which assumes a view point at the center of the cylinder and a view direction perpendicular to the screen surface. This rendering method produces correct stereoscopic depth over the full 360 degree viewing environment (Simon et al., 2004). It provides all viewers with a valid stereo image.

A serious drawback that Vincent Chapdelaine Couture and others argue is that omnistereo rendering method only produces correct imagery for viewers located at the center (Couture et al., 2010). In spite of this criticism, according to observations on the experience of the hundreds of visitors in AVIE360, McGinity and his group argue that omnistereo images can be viewed comfortably from any position inside the AVIE360 theatre.Therefore, this is the principal advantage of a cylindrical screen over planar projection systems (e.g. CAVE), because it has no corners. The possible explanation is that any image distortions generated by the discrepancies between user's position and the image viewpoint are continuous over the whole screen, and consequently less perceptible. Still, there is an obvious drawback when the visitor moves while viewing the scene in *PureLand*, the apparent lack of motion parallax causes the viewer to perceive motion in the image though there is none.

Tracking

12 infra-red cameras are distributed at different locations above the theatre, providing full coverage of the entire AVIE arena. 20 infra-red flood lights provide illumination. McGinity, Shaw and others claim that there are two tracking algorithms running at the same time, in order to provide real-time unencumbered tracking of visitors' movements and gestures (McGinity et al., 2007). This hybrid system offers the primary human-computer interface (HCI) for AVIE360.

The first algorithm uses images from all the 12 infra-red cameras to construct a voxel representation of all entities inside the theatre (Penny et al., 1999). The voxel resolution is enough for capturing limb and head from visitors. Therefore, this allows AVIE360 to keep track of individuals and detect them when they come in to contact with one another and estimate their head position.

The second system is sufficient to do a more accurate tracking such as finger(s) tracking, this provides more options and possibilities on different interaction features and designs.

3.2.3. The Virtual Tour Guide and Personal Discovery

PureLand provides two modalities of operation: the '*Guided Tour*' and the '*Personal Discovery*' mode.

The guided tour is where an expert 'tour guide' provides the audience with a scripted tour and commentary. It aims to mimic the real-world experience of going to visit one of the caves (i.e. Cave 220) as a tourist and being taken on a tour by a tour guide with a default fixed path.

On the other hand, the personal discovery mode provides another alternative active way for the audience without a tour guide to experience the virtual heritage. It allows visitors to individually and autonomously explore all the features in the cave. Visitors are given an iPad-liked menu, and they have some freedom to choose his/her order of experiences. According to the interview with Jeffrey Shaw, he mentioned that Dunhuang Academy tend to put things into order, implying this is the normal/default path, then audience can control the timing. In a certain way, this is neither typical of the narrative trajectory in his artworks, nor typical of what he originally intended. His ideal way of implementation would be a completely open-ended journey for audience, where the audience could control it on their own terms, forge their own path and determine the

duration of how long he/she spends in each place (Shaw, 2019). The active user would take other visitors, who are watching, along with them on his/her journey.

The feature of self-discovery mode among a large group of visitors in museum will be discussed in more detail in the following paragraphs.

3.2.4. Visual and Interaction Design

According to Fabrizio Galeazzi, there are different amount of animation techniques used in *PureLand* (Galeazzi, 2012). They are:

1) 2D cutouts, for instance the seven Medicine Buddha's appear to emerge out of the original mural and are repainted in their original colorful state.
2) 2D animation, for instance Samantabhadra Bodhisattva moves and comes to life. It is animated by 25 hand painted pictures for each second of footage.
3) 3D animation, such as the orchestral instruments and the Medicine Buddha's canopies converted into three-dimensional solid objects that float and rotate in front of the actual painting.
4) 3D digital recording live video, it is a live 3D video made of dancers from the Beijing Dance Academy who reenact the dances shown in the mural painting on the wall bring them to life.

None of this lively presented information is displayed in the real caves. According to the additional innovative hybrid representation, it provides a new experience for visitors to see the 'invisible'.

These animation techniques were supplemented by some digital effects generated with software, for example, the 'virtual torch light'

and 'virtual magnifier'.

Two main interactive elements are offered to user. The '*Virtual torch light*' allows the viewer to simulate moving a torch light around in the cave in order to navigate and focus

on their interested section. The '*Virtual magnifying glass'* allows the viewer to zoom into the painted surface of the mural and its details in a photo-realistic ultra-high resolution.

3.3. Features of user experience of PureLand in AVIE360

3.3.1 Peripheral vision and awareness

In a shared 360-degree stereoscopic projection environment, when you have a group of people together sharing an experience when exploring virtual heritage, *PureLand* creates a sense of social involvement. There is a chance for social exchange which is enriching visitor's experience.

According to Shaw, he mentioned that peripheral vision is not simply explained as the same as the words, there is also an importance of peripheral awareness, which creates a sense of shared experience (Shaw, 2019). To be specific, it means a lot of the visitors are sharing their emotions, for example, if you are immersed in a tour with a group, the tour group has a certain coherence and a sense that people share, exchange, or talk about their experience as well as inspire each other. This kind of social awareness in a group situation in virtual reality environments is discussed in (Benford et al., 1994), they discussed extensively the social significance of space as a resource for activity and interaction in virtual environments. They argue that continual awareness of others allows people to flexibly modify their own behavior in social situations.

This user experience feature is an advantage especially when applying it in a museum or public exhibition situation, because they are spaces for social experience and exchange. People usually visit museum and explore cultural heritage encounters with other people, like their friends and relatives. This provides a unique social experience in museological content. Also, users can be more immersed as a 'tourist' when the virtual heritage can be experienced socially.

3.3.2. Multiple identification: Performer and spectator

PureLand designed in AVIE360 aims to provide a shared experience in a museum base. Yet, as a multi-user system and application, there is a limitation of control, because only one active user can be an interactor, while the others are passive observers.

According to this limitation, Shaw expressed his opinion that he thinks when visitors go to a museum or public exhibition, it is not necessary to offer everybody autonomous

experience and those visitors would not expect this. Somehow, as a tourist or audience, users enjoy being spectators as well as interactors. He emphasized that users do not have to be an interactor to benefit from all the quality of the experiences. However, the application has to be ensured and designed as a both meaningful and satisfying interactor and everybody else who are watching the consequence of these interactions. (Shaw, 2019)

Therefore, participating in an interactive work (i.e. Virtual Heritage application) within the context of a museum/public space implies engaging with spectacle and a form of audience performance. As stated by George Legrady, the experience is performative in the sense that the user is engaged as both performer and spectator (Legrady,1999). When performing through the interaction with the work, the function of the spectator occurs via the observation of what other audience members do in performance mode. As a result, the visitors' (especially spectators') engagement is a necessary component of an interactive work, because it positions the observers into creating a sense of presence, and it is through the audience's actions that the work can reveal its complex layering of choices and multiple events.

Another interesting fact is the interactor in *PureLand* is just a member of the audience, the person who operating or controlling the interactions is not an expert; he/she can be anyone. This mean the interactor is not somebody with a different level of skills or have different understanding. All the audience is coming to the virtual heritage work with the same level of curiosity as others who exploring the work in the same way. This helps create a strong sense of identification, as you identify with the person who is exploring, because that person is at the same level as you, and at the same space and position as you.

Shaw brought out another feature: the work has infinite range of expression when every audience member operates an interactive experience in their own personal unique interpretation (Shaw, 2019). This factor is very important, because this means, as a user, he/she can look at the work through somebody else's perspective when exploring culture heritage. It gives participants a sense that the 'performer' is taking them on a journey. Notwithstanding, it is different from an experience that they are being guided by a tour guide on a journey, because it is very personal and intimate, as the performer is another typical visitor who lets you to participate in their heritage journey through the work. In addition, each person will perform, navigate and interact with the cave in a different way.

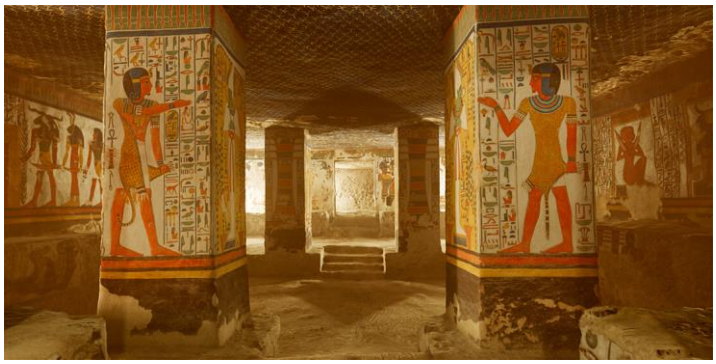
So, *PureLand* in personal discovery mode, has many possibilities of expression and exploratory experiences.

Chapter 4.

Case Study 2 – "Nefertitri: Journey to Eternity" in HMD

4.1. Project Background

Nefertari: A Journey to Eternity is a virtual heritage VR experience produced by Simon Che de Boer and his VR company *RealityVirtual* in New Zealand, which uses advanced high-end photogrammetry, visual effect techniques and Artificial Intelligence to create an amazingly detailed experience that restores and brings back the ancient Egyptian Queen Nefertari's tomb, to its original glory.



Nefertari was known as the most famous and beautiful queen who is one of the five wives of Ramses II. Every centimeter of the walls in this tomb was built for her. Similar to the situation of *Dunhuang Mogao*, while preservation attempts have been made, the site is still extremely fragile, and is not able to open for public/tourist access. Therefore, bringing it to virtual reality benefits many people, because they can have access to the tomb that is currently off limits to tourist.

Nefertari's tomb is hailed as one of the finest in Egypt and now it is accessible via SteamVR. Visitors can explore and experience its exquisite detail with their VR headset without geographical limitation, and get closer to the real experience with a personal tour of the tomb, from home or anywhere else you have a VR headset.

Current HMD platforms seldom have significant types of published virtual heritage applications. *Nefertari: Journey to Eternity (2018)* is free on Steam and Viveport, thereby offering a prescient glance at what the future of photogrammetry and portable virtual heritage experiences can provide the general public with in VR.

4.2. Generation of the Presentation

4.2.1. Technical Description of HMD

The VR system of *Nefertari* in SteamVR is HTC Vive *(Figure 2)*, a common but advanced VR headset for domestic room-scale VR. Basic components are: the headset, which offers user an individual, immersive experience; two wireless, hand-held controllers, for performing interactions; and, two 'Lighthouse' base-stations, for tracking the user's movement. The visit in HMD (in this case via the HTC Vive) offers the possibility of experiencing the tomb from a real-person point-of-view and interaction perspective. In order to do so, the controlling positions have been defined by the possibility of the user's free movement.

Figure 2

A short summary on technical specifications of the HTC Vive (Kersten, 2017) are as follow:

1) Visual: The headset provides 2 screens with a field of view of around 110 degrees for each eye, and each screen has a display with 1080x1200 resolution (2160x1200 in total), and a 90Hz refresh rate.
2) More than 70 gyroscope, accelerometer and laser position sensors suffice to detect an accurate user-position in real time.
3) Tracking: tracking space for user operation is about 4.6 x 4.6 meters, using the two "Lighthouse" base-stations for tracking the user's movement with sub-millimeter precision, by emitting pulsed infrared lasers.
4) Input Control: two SteamVR tracked wireless motion controllers with a trigger button and a trackpad.

4.2.2. Features of the HMD System Design

Fully immersive, head-mounted design

Immersion refers to a level of sensory fidelity which depends on measurable system attributes (Slater and Wilbur,1997). As mentioned, depth curing through stereoscopy is an essential feature of HMD that enhances the sense of immersion. The HMD uses a gyroscope, accelerometer, and laser position sensor to precisely check user's head position and movements. Furthermore, when experiencing the tomb through the HMD, it (the virtual environment) is visible all around the virtual subjects, i.e. the painted walls, ceilings and floors. The subject will never lose immersion when the viewer looks up or down. Even so, the sense of immersion, that is the notion of 'everywhere' is misleading whenever the user has to turn his/her head to see and explore the virtual Nefertari's tomb. By observation and the personal experience, this issue is related to 2 reasons caused by the device (HMD) limitations.

The first problem is that the field of view (FOV) in the HMD is commonly around 110 degrees. However, this is significantly less than the actual field of view of the human eye. Human FOV is around 190 degrees, in the horizontal dimension, and 120 degrees, in the vertical dimension (Henson, 1993).

Secondly, the viewer has to turn his/her head to see the virtual world in HMD, This means graphics computing will cause temporal delay (latency). According to Benny Liebold, latency means a perceived non-stability, which causes breaks in the sense of presence (Liebold, 2016). For example, when the user is completely immersed in the virtual tomb, it gives him/her a sense of 'being there', but when latency happens, after the viewer turns their head, it suddenly leads to a sense that the current experience is not realistic.

Physical and locomotive movement

The user can either physically walk within the 4.6 x 4.6 meter set-up space, or, using the 'teleport' function, beam themselves around the virtual space. As *Nefertari* did not provide a passive flying or leading path, the user can move freely inside the tomb with total self-control. However, the virtual tomb is way bigger than the physical walkable space, therefore a teleportation locomotion method is adopted to solve this problem. By

using the controls of the HTC Vive device, the user can select a destination with the teleport button. This allow the user to 'jump' from the current virtual position to another destination without any physical movement (See *Figure 3*).

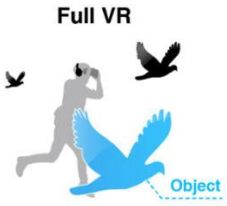
Figure 3

Although, the teleportation locomotion method can be effective for overcoming the problem of moving in the simulated space with comparatively limited walking space in the real setup, and it allows the user to move without a lot of motion sickness, it is still not the most intuitive way to explore the virtual heritage environment. According to Roy A. Ruddle and Simon Lessels, natural walking is considered to be the most intuitive way to explore in virtual environment (Ruddle and Lessels, 2009)..

Somehow, when users are totally mounted in virtual worlds, when they keep using the teleport function inside the tomb, sometimes they may get lost easily and confused as to the current location, where he/she is standing.

Binaural Audio System

Binaural audio is a method for recording and reproducing audio in 3D. In Virtual Reality, 3D audio is a very important component for creating realistic, immersive experiences.



It allows users to hear true 3D sounds, even though a simple pair of headphones. Binaural Audio can immerse users in the scene more than ever before, because of the user interaction factor (Earick, 2017).

The 3D sound used in *Nefertari* delivers different levels of impressiveness. This feature will be discussed later.

4.2.3. Visual and Interaction Design

Users can hold the HTC Vive wireless controller as a hand held flashlights, which gives the user a sense that he/she is truly discovering the 520 square meters of tomb, underground and far away from the modern-day tourist groups.

When the user explores around the tomb, he/she can point the controller towards the wall paintings and press the trigger button (see Figure 4), in order to trigger the tour guide's voice, which is incorporated in the VR experience. As such, viewers can learn about Nefertari's life and death during the tour, which captures the tomb's vivid paintings, countless hieroglyphs and depictions of ancient gods.

Figure 4

With the binaural audio technique in HTC Vive, when the user walks around, the triggered tour guide's voice will adjust its volume and direction according to the distance from, and direction in relation to, the player's position.

4.3. Features of user experience of Nefertari in HMD

4.3.1. Solitary and Isolated immersive experience

HMDs tended to isolate the user who is blocked out of the real world around them. As such the user becomes completely engaged in the virtual heritage site and the content that is presented in the HMD. Although the idea of minimalism and isolation is not a common way of visiting or experiencing cultural heritage, the powerful mechanical minimalism,

isolation and separation give its users an opportunity to be alone with their thoughts. Two separate studies, conducted at the University of New York and University of Virginia, shows that isolation has been linked to a higher capacity for concentration (cited in Thorpe 2015). The information and the discursive content become reinforced when viewed by a solitary audience. Thus, this allows a heightened level of immersion and engagement. Will Freeman discusses the power of isolation in HMD, the power of isolation offers a space for the user to feel he/she is transported to is remarkable and perhaps it is more impactful if user is experiencing the virtual content individually (Freeman, 2017).

However, taking safety issue in account, the 'chaperone' is applied in *Nefertari* while exploring it with HMD. The SteamVR chaperone component is used to display the soft and hard bounds of the VR interaction area to user, it prevents the user from obstacle collision in the physical space *(*see *Figure 4)*. Although it is a good consideration of safety for HMD, it creates another issue when experiencing *Nefertari* with the chaperone system.

Figure 5

According to observations and the user feedbacks in the SteamVR forum, the display of the chaperone breaks user immersion. When the user is totally immersed in the virtual heritage site of the *Nefertari* underground tomb, being presented with the virtual cage boundaries within the virtual environment can be a little jarring. However, users can choose to turn it off in the HMD settings, but it causes another issue that user does not have any feedback relating to whether they are near the edge of the real-world boundaries. When users collide with or hit real-world obstacles which do not exist in the user's current vision, it breaks the sense of presence in the virtual world too.

Apart from this, when the user puts the HMD on, they no longer recognize their own body. In *Nefertari*, there are no designs for an avatar of the subject's own body. Benjamin

Lok stated that when a user equipping an HMD perceives the virtual world from a first-person viewpoint, but the perception of the user's real body is completely blocked (Lok et. al, 2003).

Also, in the interview with Jeffrey Shaw, he expressed the drawback on HMD without a user body representation. It feels more mentally insecure because user lost his/her peripheral vision of his/her body. He described it as 'walking half-blinded' in the virtual world (Shaw, 2019). In other words, it leads to a disembodied experience.

4.3.2. Complete Autonomous Control

The HMD provides the user with a private and completely personal journey of discovery, without any surrounding distractions, outside the virtual content. The stereoscopy allows user to view the tomb and walk around with his/her own perspective as well as navigate according to his/her own desire. The user can look very closely at the detail, simply by moving his/her head without any virtual auxiliary tool. One of the producers of *Nefertari*, Che de Boer emphasized the graphical detail is an essential part of the VR experience (Caballar, 2018). Whereas a lot of people are overwhelmed by detail, they do not realize what is actually there, but the lighting, mood and all, feels like it is real on an artistic level. As an interactor, full self-navigation and interaction provide more freedom and independence, in an active way, which enhances the user satisfaction.

Chapter 5.

Compare and Contrast

	HTC Vive (HMD)	AVIE360
Stereo3D	✔	✔
Field of view	100 (Horizontal) 110 (Vertical)	360 (Horizontal) 44 (Vertical)
Resolution	2160x1200 pixels	22,000 x 1750 pixels
3D Spatial Sound	✔	✔
Imaging method	Head Tracking	Omnistereo
Walking Area	4.6 m^2	7.3 m^2
Audience	1	20 – 40 (flexible)

Table 1: General Specification Comparison between 2 Systems

5.1 Sense of Presence and immersion

When the simulated environment mimics, or is based on, the current physical environment, the construction of presence may not be experimental or measurable. Presence, or the experience of "being there", may only be achieved when the simulated environment and the physical environment are dissimilar (Moss and Muth, 2011). An individual may simply not think that he or she is "there", when the "there" is extremely similar to the current "here." More presence may exist or be felt when an individual is in an unlikely, or an unfamiliar environment. According to the above statement, HMD and AVIE360 attain immersion and presence.

In terms of immersion, people may argue that using a HMD VE for a simulated tangible heritage site scenario in a real-world setting may reach higher levels of immersion, because it provides an immersive environment with stereoscopic vision (first person perspective), which fully immerses the user by isolating them from the others and the real world, in order to immerse the user into the virtual world.

<u>Field of View</u>

Some of the general limitations that AVIE360 has concern the Field of View (FOV), the contrast of the projection or the surface reflection. For example, AVIE360 provides a wide horizontal FOV, but the vertical FOV is also important for the sense of immersion (Piryankova, 2015). AVIE360 offers a relatively small vertical field of view, approximately one third of the natural human vertical range (44 degrees). For a centrally located viewer, this diminishes the sensation of immersion.

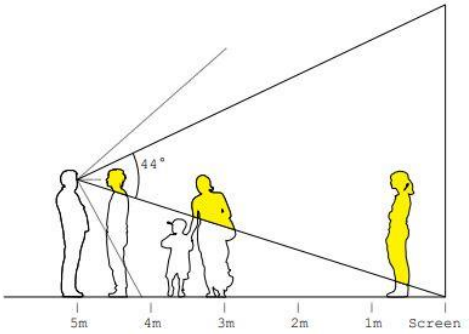


Figure 6: The visible area (yellow portion) Typical vertical field-of-view of human vision (the thin dotted line)

On the other hand, a HMD offers a relatively higher vertical FOV than AVIE360, even though HMDs also have a limited FOV. Still, this might be beneficial for the sense of immersion in the virtual environment.

Body and mental participation / embodiment

In terms of embodiment, Cathal Joseph McManus emphasizes stated the importance of manifesting users in an embodied form when they are having virtual experience (McManus, 2016). The user can experience presence in that virtual environment when there is a user embodiment. Kevin Brooks emphasizes that an important attribute of the museum space, or any 3D virtual environment, is that participants have an opportunity to physically and mentally participate and it is always important to engage users' minds (Brooks, 2003). Concerning virtual heritage applications in VR, there is typically no representation of the user's body in the HMD, while in AVIE360, the embodiment is natural, because the user can see and interact with their own body. The HMD loses the body engagement, thereby affecting the user's mental participation.

Co-Presence (Peripheral Awareness)

AVIE360 has a unique form of co-presence. Users in an immersive virtual environment can have the feeling of presence, while a group of users connected to the same immersive

virtual environment can experience copresence, that is, the sense of 'being there together' (Slater et al., 2000). This does not exist currently in virtual heritage experiences in HMDs, because the user is consistently alone in the virtual environment. AVIE360 allows multiple participants to enter a virtual environment together may increase the chance of social presence, and Jean Lave and Etienne Wenger agree that learning is transmitted, discovered and experienced better with others (Lave and Wenger, 1991).

Moreover, the presence of other participants in AVIE360 helps to enhance the spatial perception and immersion, by offering occlusion cues and natural parallax. This can be powerful when audiences are deeply embedded 'within' the virtual scenery, because it suggests that using real-world objects in conjunction with virtual imagery can be a way to increase immersion.

Although current advanced technology proposes the use of online avatars for achieving multiple users' social participation in HMD, so far, existing virtual heritage applications in HMD have not applied this technique yet. Additionally, the social or interpersonal interactions with avatars and real humans are different. Andrew Raij and others have compared the interactions with virtual humans to those with real humans. Their experiment shows that virtual humans do not meet the high standard of expressiveness set by real humans (Raij et al., 2006). Consequently, for experiencing virtual heritage in museological contexts, and in order to provide a sense of co-presence and peripheral awareness, AVIE360 might be more suitable than HMDs, because it is a spatial setting that is conducive to social experience and cultural exchange. Apart from this, the sense of shared experience means multiple users can share their emotions in AVIE360, rather than simply experiencing these emotions individually in HMD.

Auditory Immersion

Both AVIE360 and HMDs offer 3D specialized experience of sound. The AVIE360 is designed to be a sonic medium as much as a visual one. It is furnished with a real-time surround sound, spatial system with 24 high-quality speakers, distributed around the top and the bottom of the cylindrical screen, enveloping the audience within a pervasive 360-degree field of sound. Meanwhile, HMDs like HTC Vive provide high quality headphones with a built-in amplifier that deliver an excellent audio experience, that includes a spatial sound effects, thereby heightening the sense of presence too.

These are all the elements that aim to enhance the sensation of presence: active perception in the environment, ego-motion and multimodal signal binding (McGinity, 2014). Both of the systems allow virtual worlds (meaning virtual heritage sites here) to be presented rich, spatially coherent visual and sonic signs. No matter whether engaging the virtual heritage application in virtual tour guide mode or in personal discovery mode, 3D spatial and directional sound can help to guide the audience where they should focus their attention, in order to synchronize the visual and the sound narratives. It helps the user to identify the spatial position as well. However, the 3D spatial sound in HMD might be slightly more precise than AVIE360. Similar to the image rendering method, AVIE360 is perfectly viewed when the user is standing at the center, as it uses omnistereo in order to satisfy multiple users. However, the HMD uses a head tracking method, therefore the sound and vision are presented more precisely relative to the user's orientation and position.

5.2. User Comfort & Physical

Virtual heritage applications of the AVIE360 is the exploration of 'co-evolutionary narratives', in which the participants are not only interacting with the virtual world, but with each other. Hence, it is designed for multiple user with more than 20 simultaneous users. The interface is designed to be as physically 'non-invasive' as possible. In terms of comfort, it avoids any wires, tethers, heavy input or output devices, or anything that may inhibit physical movement, or verbal or gestural communication (McGinity, 2014). In opposition, the HMD involves wearing a heavy headset, the user can feel burdened by its weight. Also, there is a limitation of unnatural physical movement with HMD due to its limited FOV. Users need to turn their head in order to view the surrounding in a less natural way, because the display cannot provide sufficient horizonal FOV as human vision.

In terms of physiology, AVIE360 vision is normal and comfortable, whereas for the HMD, the combination of accommodation and vergence leads to possible discomfort (Hoffman et al., 2008).

5.3 User navigation and movement

User movement and navigation is a key component when exploring the cultural heritage site in VR.

The HMD allows users to partially walk (physically) and to move around within room scale, but users are limited by the size of the physical tracking space (4.6 x 4.6 meters). In order to overcome this limitation, different locomotion methods are introduced in HMD. The current standard method of movement in HMD is teleportation. As mentioned in the pervious case study, users need to aim at an area and press the trigger button on the provided hand controller. Then the user will be teleported to the desired position. In the HMD, teleportation is preferable to physically walking, because it can reduce the effect of cyber sickness. Still, natural walking is regarded as the most instinctive way of exploring a virtual environment. In addition, teleporting may break the immersion and it limits the distance and time for 'cooldown' that needs to be made. Yet, AVIE360 provides a large shared physical space for audiences to completely explore by natural, physical walking without the above issues caused by the HMD.

5.4. Graphical realism, end-users and engagement

The graphical representation or the level of realistic representation is one of the significant dimensions of virtual heritage. Maria Roussou and George Drettakis argue that virtual heritage applications consider photorealism as one of the most important features of successfulness in cultural heritage site representation (Roussou et al., 2003). According to Erik Malcolm Tost and Champion, graphic realism is one of the main factors which effect the end-user's engagement (Tost et al., 2007). The level of photo-realism in graphical representation relies on the VR medium's (hardware), technical support (expertise) and the level of detail captured at the creation stage.

In AVIE360, although there are still some technical challenges for panoramic photography, *PureLand* in AVIE360 successfully provides a truly 1:1 scale virtual facsimile by using the data sets. According to Shaw, they have recently achieved the maximum resolution with new panoramic video up to 11,000 pixels (Shaw, 2019). Therefore, AVIE360 can provide a relative photorealistic visual experience with ultra-high-resolution graphics, videos and animations.

Comparing the maximum resolution between AVIE360 and HMDs, the HMD is slightly lower than AVIE360. Even so, *Nefertari* in HMD used digital scanning to virtually recreate the Egyptian tomb with many realistic paintings, and recreated them with high-resolution textures and a lot of reprojection that offer satisfactory and realistic experience for user. However, the hardware specification for the HMD to present high resolution, photorealistic graphics depends on the computer's graphic card, owned by engaging user. Furthermore, most HMDs are still facing real-time rendering problems, and the hardware performances of AVIE360 are relatively equivalent to 30 HMDs. Therefore, the graphical representation on AVIE360 might be more advanced than HMD.

5.5 Interactivity

Most of the existing virtual heritage applications would include the use of interaction in order to provide the ability to gain insight through active involvement and even modification of the experience.

In AVIE360, a simple pointing device is designed as a general-purpose interface. It is similar to most of the HMD controllers, which are encased with a 3 degrees-of-freedom (DoF) orientation sensor. In the pervious case studies, the hand controller(s) in the HMD and AVIE360 are designed to emulate a hand-held flashlight, and a number of buttons provide extra functionality.

Recently, a small tablet has been adopted in place of the pointing device and console. It provides the function of a pointing device in addition to a touch-screen to emulate the console's joystick and buttons. This offers better functionality and flexibility than the console, and it allows a more dynamic, reactive and context-sensitive interface (McGinity, 2014) for the virtual heritage application in museological, or public exhibitable, practices.

Another advanced interaction device in AVIE360 is the *Immersitrack* system, which includes real-time construction of 3D voxel models of the user and a pointing gesture tracking algorithm for users to perform interactions with their fingers, as a natural user interface (NUI). This multi-user tracking function provides a lot of possibilities and flexibility for user interaction design within AVIE360 virtual environment system.

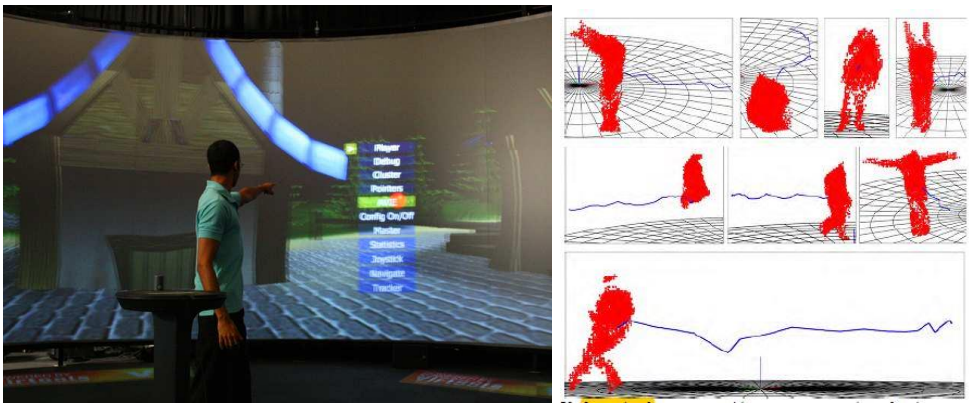


Figure 7 Immersitrack gesture recognition system can recognize multiple actions, like jumping, running, walking, crouching etc.

image from (Sridhar,2012)

In contrast, most of the existing HMDs, for example Oculus Touch and HTC Vive, only provide a 6 DoF controller, which can track the user's hand positions and their orientation and movement, thereby letting users physically move their hands around in a virtual world instead of using gestures to guide it. Although some third-party external NUI devices (e.g. Leap motion) can be attached to the HMD (on the user's forehead) in order to let the user perform natural hand-free interactions, this is not currently implemented in virtual heritage applications for the HMD.

Besides the comparison of interaction devices between the AVIE360 and HMDs, the HMD has a feature that it allows the user complete autonomous control over his/her own experience. That is, the HMD user is given full control and privilege of interactions in their virtual experience, while AVIE360 does not have this characteristic. By recapping Shaw's statement, in museological contexts, it is not necessary to offer everybody an autonomous experience, as AVIE360 aims to satisfy both interactors and spectators among the group of audience. Although only single users can be an interactor, every user brings their own personal interpretation. As everybody will interact in a different way, no person who operates such an interactive experience will do it in the exact same way as somebody else. This means that the experience has an infinite range of expression. Users in AVIE360 have the pleasure of seeing the experience through somebody else's eyes, sharing the world, and being in ecology of a social engagement, HMDs cannot thus far offer such a user experience paradigm.

Chapter 6.

Conclusion and Future Works

Conclusion

This paper has added to the body of knowledge concerning the user experience of cultural heritage in VR by considering the experiential differences between the HMD and AVIE360 systems.

By combining theoretical analysis with case studies on both systems, a comprehensive comparison on the viewing conditions (i.e. field of view, image rendering methods and graphical representation), auditory systems, user navigation, movement and interactivity methods, the research measures how these technical conditions influence the user experience (the sense of presence, engagement and immersion) in AVIE360 and HMDs. In addition, a further comparison on user comfort, physical and peripheral awareness, and social engagement have been put into account.

To sum up, both the HMD and the AVIE360 offer a very special and engaging experience in different ways. Both of them are satisfactory ways for exploring virtual heritage applications. It is hard to argue which is a better platform when presenting virtual heritage application, because both of them have their own pros and cons.

However, when talking about museological experience, going to museum or public space, where one would have a shared virtual heritage experience, an immersive projection environment like AVIE360 would be more suitable, because it is socially shared, and can facilitate full peripheral vision and sensibility relative to one's own body and to other people's bodies. People can naturally participate in the work either by being an interactor, or a spectator.

On the other hand, at home or individual, private spaces, the HMD can provide a solitary, fully immersive, isolated experience and complete autonomy over control in the virtual heritage application. Therefore, for further personal entertainment and deeper educational purposes, HMD may be more suitable than AVIE360.

Limitations and future works

As the existing virtual heritage applications particular to each system have never been presented on both of the system displays at the same time, there is a limitation on the selection of case studies. The above two virtual heritage applications do not have the same content, therefore, this prohibits an accurate, systematic comparison and contrast of their characteristics and their merits and pitfalls. Therefore, the applications in case studies are chosen basis of their design similarity, and that they are presented in AVIE360 and HMD respectively.

With a clearer system and technical comparison between AVIE360 and HMD, suggested future work will develop this research in three directions:

- Conduct a user experience experiment with participants there the exact same virtual heritage content will be delivered to AVIE360 and HMD. This will allow more accurate analysis of the user experience differences by collecting the data from the participants' feedback, in order to compare with the theoretical comparison results.
- Identification of the consequences of the findings, which will contribute towards the production of content design and development standards for virtual heritage projects. A design framework or guidelines can be made for AVIE360 and HMD according to the technical conditions and their benefits and drawbacks. Therefore, would results in an empirically informed assessment of and guidelines for emerging practice.
- Developing recommendations for social participation possibilities in virtual heritage projects for HMDs: According to the rapid development of sociability in VR and the use of avatars, further research on how to achieve social engagement and participation in HMD is a worthy research remit, which can help suggest new ways of designing for online social virtual heritage applications.

.

Appendixes

I. Audio transcript of the interview with Jeffrey Shaw

Q1. Do you think there is any importance on group visits/participation when people exploring virtual heritage? If so, why?

Answer:

Yes, because when you have a group of people together sharing an experience, there's a sense of social involvement, there's also an opportunity for social exchange, which is richness in your experience.

Hot topic of Peripheral vision, it is not just about peripheral vision, but also peripheral awareness. When you go to a concert and listen to music or when you go to a movie, or comedy, you are sitting to somebody who is laughing. It means a lot of thing when you hear the laughs around you. Or the person next to you is crying, it means a lot if we are sharing these emotions, rather than just experiencing these emotions individually. So, you have a sense of shared experience.

When you are on a tour with a group, the tour of group has a certain coherence of a sense of people share, exchange and talk about their experience with each other. Also, inspire each other.

For example, if I visit a museum, see somebody standing in front of a painting, looking with a numerous amount of attention of this painting, my feeling will be 'why does this person so focus on this painting?' It must be interesting. So, that person focuses his attention, attract my attention. These subtle exchanges of messages, not necessary just words but also feeling, it is meaningful and creates sense of presence, which does not have with HMD.

That's why I am so typical committed to the advantages of AVIE360 system, especially in a museum situation. People go to museum with their friends, relatives, they encounter with the people. Museum as space of social experience and social exchange. Of course, if you are sitting at home alone in front of your screen, people would have no problem with HMD as an immersive personal experience. In that situation, HMD is great for experience for individual, at home. I am not a fan of HMD, as an experience in museum logical content.

Furthermore, HMD is not so expensive, anybody can buy them. The applications can just be downloaded. Going to museum and sitting down in front of an monitor, what would you want to do that? Why would you bother to go in and look at the monitor and surf the internet in a museum? You do that at home.

We provide virtual heritage experience which can be shared socially, which can be experience socially.

Q2. (AVIE360) As a multi-user system, how do you think the limitation of control to only one active user (while the others are passive observers) and viewing conditions (i.e. Omnistereo), affect the user experience and the sense of presence/immersion?

Answer:

One active user controls the whole system, others are spectators of what that person does. If you got an HMD, you have complete autonomous control of your own experience. Again, when you go to a museum, you don't necessarily go there to offer everybody autonomous experience and I don't think people expect this. We enjoy being spectators as well as being interactors. It's very important to understand the experience which I designed, it aims to satisfy both for interactors and for spectators. You don't have to be an interactor to benefit from all the quality of the experiences. You have to be sure that work is designed to be both meaningful and satisfying interactors and everybody else who are watching the consequence of these interactions.

Another interesting thing is the interactor is just a member of the audiences. He/she is not a special person, he/she is anybody. Because it means the person who is interacting is actually just like you, he is not somebody with a different level, skills or have different understanding. This person is coming to the work with the same curiosity as you all coming to the work. Exploring the work in the same way you will be exploring as a visitor. This is important because it means you can identify with that person, that person is as same as you. This create the strong sense of identification, you identify with the person who is exploring over, because that person is at the same level as you, at the same space and position as you.

It isn't like a concert, when you have a conductor upon stage who is an expert conducting the whole orchestra. This person who operating the system is not an expert, just you. The factor is very important, because everybody does it differently. No person who operate such an interactive experience will do it in the same way as somebody else. So everybody brings their own personal interpretation. It means you are looking at the work through somebody else's eyes. And you have a sense that they are taking you on a journey. It's very personal, very intimate. This person who is another visitor, is allowing you to participate in their journey through the work. So, you are accompanying them. This is a very intimating relationship.

Then, next person will do it differently, so basically each person will perform the work in a different way. This mean the work has infinite range of expression.

In my own experience, making interactive works whenever I see my work is being performed by somebody else, it is never even the same. I can see the work being performed million times; it will be a million times different.

Somebody is taking you through to a personal journey in the work, in the way privilege to that part of journey and join them.

Some people will pay a lot of attention to this detail while others will pay a lot of attention to that detail. Different people will focus their attention in different ways. This gives the range of variety, it means you can come back and see the work a hundred times is always be different.

But HMD doesn't have this character, HMD has a privilege of having a total control by yourself, again, you don't have the pleasure of between the work through somebody else's eyes of sharing the world, of being in an ecology of a social engagement.

With HMD, people is trying to solve all these problems of social aspect on the VR experience, so they introduce the idea of 'AVATOR', so other people can enter into the world with their avatars and you can encounter with other people with avatars. This does help to begin socializing in the virtual world. This is one of the strategies to overcoming this problem, the social nature of the HMD. The internet shows us how 'social' the virtual world can become under certain circumstance. So, we can imagine that there is a path which is involved in socialization of the virtual world enjoin the HMD.

My intendancy is why would you do this in museum? Certainly, at home you may interesting to sit and put on your HMD, have a virtual cultural heritage experience which can explore with other people in other location who are also wearing the HMD.

Q3. How would you describe the differences between the 'full body' experience in AVIE360 and HMDs?

Answer:

When you put on the HMD, you amputate yourself and your eyes. This is a very serious problem, and HMD will feel 'daze' relatively small. So, we are dealing with a problem on peripheral vision. In the real world, we focus our attention. But the experience of the real world is in which by all the peripheral vision we have. We see all the way around and can look around. We have a very strong sense of the way which the world is a completed entity around us and how our eyes sensitive to all the peripheral imagery. This is lost in the HMD. HMD is just like looking through the windows. Imagine you have to live your life looking through a window, will be very uncomfortable.

Full body means in peripheral vision, even I am look down with my head, I can see my hands, I sense my body and my legs, everything is there. I am complete in the world. As soon as I put the google on into the virtual world, I basically become incomplete. Of course I can try to balance that, but I will create an avatar of my own body and putting that avatar into the virtual world, at the same time, the avatar is just an expression of abstraction of ME. That abstraction is not the same feeling as the real me.

The other thing is navigation, moving around. Of course, you can move around with wearing the HMD. But generally speaking, it feels more mentally insecure because again you lost your peripheral vision of your body. So in the way you are walking 'half-blinded' in the virtual world.

The way each one can walk around in the AVIE360 freely without any discomfort, you can sit down, stand up, lie down, you can bump into people. All these comforts of live in the real world somehow compromise when you are wearing HMD.

Q4. What are the positive qualities of the AVIE360 that would, in your view, argue that it is a better platform than the HMD for presenting virtual heritage application?

Answer:

It's not a question of 'better platform'. HMD is not a normal property in itself. It offers a very special experience, it is very engaging. I would say in certain circumstance, it would be very satisfying way of exploring virtual heritage applications. I am 100% supportive of VH applications in HMDs. Also, 100% supportive of applications in immersive projection environments.

Both of them have very specified qualities, we could say both of them have their own pros and cons. When we are talking about museological experience, going to a museum or going to a public space, where one would hack a VH experience, this need to be an immersive projection environments, some kind like AVIE360, DOME… which is socially shared, able full peripheral vision and peripheral sensibility of your own body and other people's bodies.

At home, I would say yes, if I were sitting in front of my screen. HMD will give me more as an experience at home.

Q5. What are the future possibilities or developments that need to take place so that AVIE360 can be delivered to cultural heritage?

Answer:

The main challenge is you need space for social immersive experience you need space to set it up. You need money to invest it, you need to create an experience which has a real quality, high resolution that is good to look at. If you do in 3D, you have to do the 3D correctly, because when you do it incorrectly, you feel very uncomfortable.

So, basically, both from AVIE360 and HMD, the future development depends a lot on increasing the quality of the technology. In term of technology for AVIE360 is better than the technology of HMD. HMD is still limited by the resolution, field of use. The technological status of HMD is not sophisticated than AVIE360. We recently built the AVIE360 in Switzerland with 4K projectors. So we have a total resolution of 2000 pixels height, 20,000 pixels around, it's a fantastic experience with really cinematic quality. This is something you don't have with the HMD.

Certainly, the future possibilities of development are the evolution of the technologies, of course bringing out of cost as well. HMD is always going to be cheaper than the AVIE360 system. AVIE360 system can be shared among with many people, HMD is just

one individual. But still, if you say let's bring 30 people together with 30 HMDs, it still going to be cheaper. But AVIE360 still gives you enormous reward in terms of your experience.

Other future possibilities, there's a lot to do with content development. The major challenge on virtual heritage is how to create beautiful content. This depends on a lot on technique for capturing the real world, being able going on to location, being able to digitalize, further photogrammetry using drone, scanning. All these technique for capturing the real world and all the technique for rendering the virtual world.

(Introduction of Case studies 2)

Recently there is an example of a work which was created for HMD experience and it also put into the AVIE360. This is a virtual tome in Egypt – Nefertiti. This is the most brilliant example of the most up-to-date technology, because you have photogrammetry which then is supported by A.I. to create extremely beautiful 3D models based just on photography of the tome. Using A.I. algorithms to help you to build this beautiful 3D representation of the cave. Generating more and more sophisticated content behalf of this VH experiences.

Q6. Are there any other opportunities or applications that could be useful for the AVIE360? What are they?

Answer:

Now I would say, until recently for panoramic videos the maximum resolution is 8K all the way round. We have just recently putting all with the new panoramic video camera which is up to 11k resolution. So being able to have higher resolution, for panoramic video is a fantastic plus. And have a compact camera which you can carry around in record performances or retro or live situation is fantastic. Head to the next level is being able to do them into 3D, being able to capture fantastic quality in 3D panoramic videos.

Panoramic photography, there are still some technical challenges there. GB of pixels of Panoramic photography, a camera which can rotate and take hundreds of pictures, you can create a very high resolution of spherical images, this is something very mature at the moment. It's also involving.

Again, it's a lot to do with the evolution of technologies, like capturing, digitalizing the real world. Also, the evolution of technology on 3D modelling and visualization. Software like unity, unreal, really helping us to model and render very beautiful images.

Also, A.I. into the mix is the work you do in developing the visualization is supportive and machine learning. When machine learning begins to understand all the parameters of virtual heritage, it will have a big impact on the ace which we able to create and present this scene.

The graphics engines which are required, we had companies like Nvidia where you have early genesis of the graphic engine side. (?)

The AVIE system in the early days, it was only possible to generate satisfying result if we have 1 computer for each projector, 1 graphics card for each projector. But today, I can achieve a lot by 1 computer with multiple graphics cards. In 1 computer to drive an AVIE system in entirely. These are all the components, opportunities of applications in the future because as all the technologies become more and more supportive of what we trying to achieve, it gives us more flexibility and create a richer experience.

Interaction Tracking experiment, we have 30 peoples coming into AVIE system, we used cameras to track their movement in the space, so we can understand where people are in the space and we can use it as a tool to help us interpret where their interests is and tell their behaviors to the system, to the physical location of people in the space. So certainly, there is a whole range of new possibilities in terms of how we can design at the user interaction and what technology we can use to allow user to interact with the work.

Movement, gesture, behavior in the space, voice, eye tracking… without using any extra devices.

In certain interaction design in relation to the content, what the experience that you want to create, and your interaction design is telling to generate for the viewer.

I would prefer to go my own way, either or I give up my own experience, I will go with somebody else, participate in somebody else's experience. But I would prefer these 2 options, rather than splitting the screen into 30 and have to look at 30 different directions simultaneously, which will give me very little satisfaction. That is the reason why I haven't done much work in multiuser interaction, because if I give everybody their autonomy, means I need to split things up. By splitting things up, I damage the coherence of the entire experience.

There is one artist who has solved this problem in an interesting way. Perry Hoppen 'Barco Hotel?' and his solution of this problem is going to create a coherence virtual world which everybody shares, but in that virtual world, I will give everybody their own object. They have their full control on their own object. So you have a virtual world, which is shared by everybody, but everybody has independent control of their own piece of object to interact with other people's objects. This is a model which a group of people can participate together in interact with multiuser virtual world.

I have never been able to make this model works for me in a cultural heritage situation. I have never made that model be meaningful in Cultural Heritage. But I am just saying, when you want to have a multiplayer interaction, you have to face certain problems and find certain solution. And that solution has to be satisfied.

Multiuser interaction is challenging, I have no difficulties in scenarios for dealing with 2 peoples, but more people involved will be very difficult.

Additional Information:

Pureland is a virtual heritage, which is aims to mimic the real-world experience of going to visit one of the cave as a tourist and being taken on a tour by a tour guide. So, Pureland is designed as a tour by experience. It's an unusual work from my own point of view, and it's because this is what the DunHuang academy wanted. They wanted to simulate the real-world experience of being taken tour by a tour guide. It likes an immersive PowerPoint. It is a tour guide who is taking your into this immersive environment and showing you around and telling you stories about what you see. Sometimes, I have done it into active way for the audience who out of tour guide, we created an iPad with like a powerpoint in pictures, and press buttons, You just choose which button you push and it will take you to those experiences. But still, it's very much the model of a tour guide and if the our guide is not there, then you kind of have a menu, instead you have some freedom to choose your order of experiences. But we tend to put things into order, we tended to say this is the normal path, and then you just control the timing. But in certain way, no typical of what I do in my artworks and not typical of what I prefer. Well, it's completely open ended in terms of how you are ___ the journey, how long you spend in each place, it's your journey, you made it in your own term, and you take other people along with you on your journey who are watching.

We are now currently working on a new project which is called the Atlas of Maritime Buddhism, it's another important cultural heritage experience, where you can visit Buddhism sites all across of Asia from India to japan. Here also the model would be used for Hampi. This is a museum, we are making this work that will be a permanent installation and, in that museum, they will have groups of visitors, around 40 peoples who only available to visit this installation maybe for 10 minutes. For students have this constraint, it is hard to offer a meaningful interactive experience, you simply don't have the time. So, in that case, we will just have a movie, because in that 10 minutes, I can't waste time, I have to give 40 peoples rich experience and the only way I can do this is with a movie. They can come back and visit the museum on their own…

One thing you have to take into consideration when you are talking about virtual heritage experiences in museum with a thousands of visitors, it is a very salience constraint on what you can do in an interactive environment.

It just like it's very difficult to make a movie for a cinema that last for 5 hours, who's gonna sit in the cinema for 5 hours? But they solved this problem with television series. They can be 50 hours. In different content you have different solutions. Indeed, you cannot design an interactive experience for a mass public at the same time with a mass visitation and very very short time frames.

Same for HMD, you can't just turn it on for 5 minutes and then take them off, it is just like looking at pictures, it isn't a deep going experience.

II. Signed Informed Consent Form (Interview with Professor Jeffrey Shaw)

TRINITY COLLEGE DUBLIN
INFORMED CONSENT FORM

LEAD RESEARCHER:

Woon Him WONG, Lindy

BACKGROUND OF RESEARCH:

Virtual Heritage in VR not only potentially help lessen the impact of tourist erosion to protect overrun/destroyed heritage, but also provides a realistic 3D virtually reconstructed historic sites experiences as visitors, travellers or even as resident.

These kind of virtual heritage applications can be brought to different VR environment systems, i.e. portable devices (e.g. Head-Mounted Displays) as well as complex and large devices (e.g. CAVEs, Tiled Projection Displays). Most of these technologies aim to support an immersive environment for user. Many researchers focused on comparison between the performance and effectiveness between using CAVE and HMD, and the 'process' or the 'product' but less consider 'users'. Therefore, this paper examined on how different system settings influence users' experiences in virtual heritage (e.g. amount of audiences, viewing conditions, mode of interactions).

In term of user experience, this research paper tries to evaluate the differences of visual condition, behavioural interaction, feeling, sense of immersion, presence and co-presence etc. among 2 types of VR systems when using them in virtual heritage aspect. This paper focuses on comparing the Advanced Visualization and Interaction Environment (AVIE) and HMD (Head Mounted Display). Though most of the people are already familiar with HMD experience, the AVIE is a 360° virtual reality theatre which invented in 2007 and has been started using as a new form of virtual heritage in recent year. There must have unique benefits and differences among themselves, as they are co-existing in the virtual heritage market at the same time.

A comparison study on the differences of user experience in different forms of VR systems when they are exploring tangible virtual heritage. Plus, case studies of existing virtual heritage application were mentioned in this paper as actual example to review the differences on various factors between AVIE and HMD, i.e. presence, attention, concentration on content, engagement and social ease.

PROCEDURES OF THIS STUDY:

It will be a casual conversation and Q&A session oral interview via Skype. It approximately takes around 30-60 minutes. We do not anticipate any risk to participants.

PUBLICATION:

It will not be a publication, but the interview content will be recorded or transcript-ed for in/direct quotations on the research paper which is a M.Sc. dissertation at Trinity College Dublin. The dissertation may share between academic database or school platforms for records.

CONFLICTS OF INTEREST: (As for the information sheet. Repetition is not required for online forms where both information sheet and consent form are presented together).

This interview only contributes to satisfying the Master dissertation research paper. There is no any additional purposes other than academic use. It will not used in any other third party and not for advancing commercialization potential.

DECLARATION:

- I am 18 years or older and am competent to provide consent.
- I have read, or had read to me, a document providing information about this research and this consent form. I have had the opportunity to ask questions and all my questions have been answered to my satisfaction and understand the description of the research that is being provided to me.
- I agree that my data is used for scientific purposes and I have no objection that my data is published in scientific publications in a way that does not reveal my identity.
- I understand that if I make illicit activities known, these will be reported to appropriate authorities.
- I understand that I may refuse to answer any question and that I may withdraw at any time without penalty.
- I understand that I may stop electronic recordings at any time, and that I may at any time, even subsequent to my participation have such recordings destroyed (except in situations such as above).
- In some situations, it will not be possible to withdraw consent for recordings, e.g. if a public data set has been published, as allowed for in the initial consent, if so, then detail up to what point recordings can be destroyed.
- I understand that the research team will remove such recordings where possible, but if the recordings have been published or made publicly available, with my original consent, then this will no longer be possible.
- I understand that, subject to the constraints above, no recordings will be replayed in any public forum or made available to any audience other than the current researchers/research team.
- I freely and voluntarily agree to be part of this research study, though without prejudice to my legal and ethical rights.
- I understand that if I or anyone in my family has a history of epilepsy then I am proceeding at my own risk.
- I have received a copy of this agreement.

By signing this document, I consent to participate in this study, and consent to the data processing necessary to enable my participation and to achieve the research goals of this study.

PARTICIPANT'S NAME: Jeffrey Shaw

PARTICIPANT'S SIGNATURE:

Date: 21st Mar 2019

Statement of investigator's responsibility:

I have explained the nature and purpose of this research study, the procedures to be undertaken and any risks that may be involved. I have offered to answer any questions and fully answered such questions. I believe that the participant understands my explanation and has freely given informed consent.

RESEARCHERS CONTACT DETAILS:

(Email) wwong@tcd.ie
(Mobile) +353 0857445618

RESEARCHER'S SIGNATURE:

Date: 21st March 2019

Bibliography

Armstrong, M., 2017. Infographic: Where World Heritage Sites Are Under Threat [WWW Document]. Statista Infographics. URL https://www.statista.com/chart/11812/where-world-heritage-sites-are-under-threat/ (accessed 4.19.19).

Guttentag, D.A., 2010. Virtual reality: Applications and implications for tourism. Tourism Management 31, 637–651. https://doi.org/10.1016/j.tourman.2009.07.003

Shaw, Jeffrey. 2019, March 22. Skype personal interview.

Arnold, C.J., Huggett, J.W., Reilly, P. and Springham, C. 1989 'A case study in the application of computer graphics' in Rahtz, S. (ed) Computer Applications and Quantitative Methods in Archaeology 1989. CAA89, British Archaeological Reports International Series 548. Oxford: Archaeopress. 147–55. http://proceedings.caaconference.org/paper/15_arnold_et_al_caa_1989/

Guo, F., 2012 'More Than Usability: The Four Elements of User Experience, Part I' [WWW Document]. UXmatters. URL https://www.uxmatters.com/mt/archives/2012/04/more-than-usability-the-four-elements-of-user-experience-part-i.php (accessed 4.22.19).

E. Lantz. The future of virtual reality: head mounted displays versus spatially immersive displays (panel). In Proceedings of the 23rd annual conference on Computer graphics and interactive techniques, pages485–486. ACM, 1996

Slater, M., Wilbur, S., 1997. A Framework for Immersive Virtual Environments (FIVE): speculations on the role of

Presence: Teleoperators and Virtual Environments. MIT Press, Cambridge, MA, USA. 6, pg. 603–616.

Burdea, G. C., & Coiffet, P., 2003. Virtual reality technology (Vol. 1). Hoboken, NJ: John Wiley & Sons.

Guttentag, D. A., 2010. Virtual reality: Applications and implications for tourism.Tourism Management,31(5), 637–651.doi:10.1016/j.tourman.2009.07.003

Cruz-Neira, C., Sandin, D.J. and DeFanti, T.A., 1993, September. Surround-screen projection-based virtual reality: the design and implementation of the CAVE. In Proceedings of the 20th annual conference on Computer graphics and interactive techniques (pp. 135-142). ACM.

Dominjon, L., Lecuyer, A., Burkhardt, J.M., Andrade-Barroso, G. and Richir, S., 2005, March. The" Bubble" technique: interacting with large virtual environments using haptic devices with limited workspace. In *First Joint Eurohaptics Conference and Symposium on Haptic Interfaces for Virtual Environment and Teleoperator Systems. World Haptics Conference* (pp. 639-640). IEEE.

Kulik, A., Kunert, A., Beck, S., Reichel, R., Blach, R., Zink, A. and Froehlich, B., 2011, December. C1x6: a stereoscopic six-user display for co-located collaboration in shared virtual environments. In *ACM Transactions on Graphics (TOG)* (Vol. 30, No. 6, p. 188). ACM.

Tan, B.K., Rahaman, H., 2009. VIRTUAL HERITAGE: REALITY AND CRITICISM. Conference proceedings.

Carrozzino, M., Bergamasco, M., 2010. Beyond virtual museums: Experiencing immersive virtual reality in real museums. Journal of Cultural Heritage 11, 452–458. https://doi.org/10.1016/j.culher.2010.04.001

Mestre, D. R. J. E. I., 2017. "CAVE versus Head-Mounted Displays: Ongoing thoughts." 2017(3): 31-35.

Gaitatzes, A., et al., 2001, Reviving the past: cultural heritage meets virtual reality. Proceedings of the 2001 conference on Virtual reality, archeology, and cultural heritage, ACM.

McGinity, M., Shaw, J., Kuchelmeister, V., 2007. AVIE: a versatile multi-user stereo 360 ° interactive VR theatre [WWW Document]. ResearchGate. URL https://www.researchgate.net/publication/220720600_AVIE_a_versatile_multi-user_stereo_360_interactive_VR_theatre (accessed 4.22.19).

Systems – EMPLUS, n.d. URL https://emplus.epfl.ch/systems/ (accessed 4.29.19).

McManus, C. J., 2016. Down the Rabbit Hole: Feeling Present in Virtual Reality.

Bourke, P.2004. Edge blending using commodity projectors http://local.wasp.uwa.edu.au/~pbourke/texture_colour/edgeblend/

Couture, V., Langer, M.S., Roy, S., 2010. Analysis of Disparity Distortions in Omnistereoscopic Displays [WWW Document]. ResearchGate. URL https://www.researchgate.net/publication/220244915_Analysis_of_Disparity_Distortions_in_Omnistereoscopic_Displays (accessed 4.29.19).

Galeazzi, F., 2012. Pure Land Inside the Mogao Grottoes at Dunhuang. [WWW Document]Academia.URLhttps://www.academia.edu/5892049/Pure_Land_Inside_the_Mogao_Grottoes_at_Dunhuang

Benford, S., Bowers, J., Fahlen, L.E., Mariani, J., Rodden, T.,1994. Supporting Cooperative Work in Virtual Environments, The Computer Journal 37(8), 653-668.

Legrady G.,1999. Intersecting the Virtual and the Real: Space in Interactive Media Installations, Wide Angle 21.1 105-113

Henson, D.B., 1993. Visual Fields. Oxford: Oxford University Press.

Liebold B., Brill M., Pietschmann D., Schwab F.& Ohler P.,2016. " Continuous Measurement of Breaks in Presence: Psychophysiology and Orienting Responses", Media Psychology, pp 1-26,

Ruddle, R.A., Lessels, S., 2009. The Benefits of Using a Walking Interface to Navigate Virtual Environments. ACM Trans. Comput.-Hum. Interact. 16, 5:1–5:18. https://doi.org/10.1145/1502800.1502805

Freeman, W., 2017. "Antisocial VR" and the power of isolation. GamesIndustry.biz.

Thorpe, J.R., 2015. 6 Psychological Benefits Of Spending Time Alone [WWW Document]. Bustle. URL https://www.bustle.com/articles/126782-6-psychological-benefits-of-spending-time-alone (accessed 5.3.19).

Slater, M., Sadagic, A., Usoh, M., and Schroeder, R., 2000. Small-group behavior in a virtual and real environment: A comparative study. Presence: Teleoperators and virtual environments, 9(1): 37–51

Lave, Jean, and Etienne Wenger. 1991. Situated Learning: Legitimate Peripheral Participation. Cambridge: Cambridge University Press.

Raij, A., Johnsen, K.J., Dickerson, R.F., Lok, B., 2006. Interpersonal Scenarios: Virtual approx Real?

Piryankova, I., 2015. The influence of a self-avatar on space and body perception in immersive virtual reality. Logos Verlag Berlin GmbH.

McGinity, M., 2014. Presence, immersion and the panorama - a theoretical, technical and artistic inquiry into the nature of presence and immersion in virtual reality.

Brooks, K., 2003. There is Nothing Virtual About Immersion: Narrative Immersion for VR and Other Interfaces.

Hoffman, D.M., Girshick, A.R., Akeley, K., Banks, M.S., 2008. Vergence-accommodation conflicts hinder visual performance and cause visual fatigue. J Vis 8, 33.1–30. https://doi.org/10.1167/8.3.33

Roussou, M., Drettakis, G., 2003. Photorealism and Non-Photorealism in Virtual Heritage Representation 11.

Tost, L.P., Champion, E.M., 2007. A Critical Examination of Presence Applied to Cultural Heritage. In: The 10th Annual International Workshop on Presence, pp. 245–256

Sridhar, A., 2012. Combining Computer Vision and Knowledge Acquisition to Provide Real-Time Activity Recognition for Multiple Persons within Immersive Environments. (PhD), University of New South Wales, Sydney.

Lok, B., Naik, S., Whitton, M. C., and Brooks, F. P. 2003. Effects of handling real objects and self-avatar fidelity on cognitive task performance and sense of presence in virtual environments. Presence: Teleoperators and Virtual Environments, 12(6):615–628