Virtual Guidance using Mixed Reality in Historical Places and Museums

MuseumEye—a HoloLens-based Mixed Reality Guide to the Egyptian Museum in Cairo

Ramy Hammady

1st Supervisor: Prof. Minhua Ma, 2nd Supervisor: Dr. Polina Zioga

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Dedication

This dissertation is dedicated to my brilliant and supportive wife, Fatma Mahfouz, and to my always encouraging, ever faithful parents, Mamdouh Hammady and Maha Elwaraki.

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Abstract

Mixed Reality (MR) is one of the most disruptive technologies that shows potential in many application domains, particularly in the tourism and cultural heritage sector. MR using the latest headsets with the highest capabilities introduces a new visual platform that can change people's visual experience.

This thesis introduces a HoloLens-based mixed reality guidance system for museums and historical places. This new guidance form considers the inclusiveness of the necessary and optimised functionalities, visual and audio guiding abilities, essential roles of a guide, and the related social interactions in the real-time.

A mixed reality guide, dubbed 'MuseumEye' was designed and developed for the Egyptian Museum in Cairo, to overcome challenges currently facing the museum, e.g. lack of guiding methods, limited information signposted on the exhibits, lack of visitor engagement resulting in less time spent in the museum compared to other museums with similar capacity and significance. These problems motivated the researcher to conduct an exploratory study to investigate the museum environment and guiding methods by interviewing 10 participants and observing 20 visitors. 'MuseumEye' was built based on a literature review of immersive systems in museums and the findings of an exploratory study that reveals visitor behaviours and the nature of guidance in the museum.

This project increased levels of engagement and the length of time visitors spend in museums, the Egyptian Museum in Cairo in particular, using the mixed reality technology that provides visitors with additional visual, audio information and computer-generated images at various levels of details and via different media. This research introduces the guidelines of designing immersive reality guide applications using the techniques of spatial mapping, designing the multimedia and UI, and designing interactions for exploratory purposes. The main contributions of this study include various theoretical contributions: 1) creating a new form of guidance that enhances the museum experience through developing a mixed reality system; 2) a theoretical framework that assesses mixed reality guidance systems in terms of perceived usefulness, ease of use, enjoyment, interactivity, the roles of a guide and the likelihood of future use; 3) the Ambient Information Visualisation Concept for increasing visitor engagement through better presenting information and enhancing communication and interaction between visitors and exhibits; and a practical contribution in creating a mixed reality guidance system that reshapes the museum space, enhances visitors' experience and significantly increases the length of time they spend in the museum.

The evaluation comprised of quantitative surveys (171 participants and 9 experts) and qualitative observation (51 participants) using MuseumEye in their tours. The results showed positive responses for all measured aspects and compares these to similar studies. The observation results showed that visitors who use MuseumEye spent four times the duration visitors spent without guides or with human guides in front of exhibited items. The quantitative results showed significant correlations between the measured constructs (perceived usefulness, ease of use, enjoyment, multimedia and UI, interactivity) and the likelihood of future use when the roles of guide mediate the relations. Moreover, the 'perceived guidance' is the most influential construct on the likelihood of future use of MuseumEye. The results also revealed a high likelihood of future use, which ensures the sustainability of adopting mixed reality technology in museums.

This thesis shows the potential of mixed reality guides in the museum sector that reshape the museum space and offers endless possibilities for museums and heritage sites.

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Contents

List of Figures

List of Tables

Chapter 1: Introduction

1.1 Background and Rationale

VR and AR are commonly known as technologies that have similar visualisation concepts; the most integral factor in VR is the synthetic world environment, generated by computer graphics. This virtual environment completely immerses the observer in a virtual world that does not have the same properties of the real world, such as gravity, time and materiality (Milgram et al., 1995). In contrast, AR is more integrated into the real world, which is limited by some virtual objects that are superimposed upon it (Wagner, 2007b). However, Wojciechowski et al. (2004) believe that the relationship between AR and VR is continuous. AR is considered an extension of VR, with the distinction of mixing virtual objects with a natural view of reality in seamless composition scenes. To sum up, in VR (Furht, 2011) the user is immersed in a virtual world created by computer graphics, whereas, AR is typically rendered in real time in the real world and in a semantic context with environmental elements.

Mixed Reality (MR) is one of the fastest growing and most highly sophisticated technologies (Kang and Tang, 2014). MR is considered an extension to Augmented Reality (AR) technology, which retrieves information and data and overlays it on a real world live feed (Liu et al., 2007). Yoon et al. (2012) suggest that there is no unified definition of AR. However, their approach is based on Azuma (1997), who advises that 'AR environments […] which include real and virtual objects in the real environment, alignment of real and virtual objects with each other, and their interaction in real time' (Yoon et al., 2012). At the same time, an old taxonomy for MR, coined by Milgram et al. (1994) combines both AR and VR technologies, whereas a new taxonomy, according to Bray (2018), also includes the capabilities of the immersive reality devices (Zeller et al., 2018b) (Prasuethsut, 2016a), which could expand to both virtual and the physical environment in a wider manner. These virtual data can be 2D, 3D, text, video, and/or animations with or without audio. The main feature that MR provides is increasing the streaming of communication between the human, the computer and the physical environment, through the most effective methods of visual communications and interactions (Billinghurst and Kato, 1999); (Bray, 2018). The users can observe real-time virtual objects, control them, and receive audio and visual information via hand interactions while wearing a Head Mounted Display (HMD) device. Recently, MR has become more prominent as it can interpret the physical environment better than AR (Zeller et al., 2018b). Also, MR better integrates the physical world with the virtual world thanks to holographic devices, such as Microsoft HoloLens (Microsoft, 2015b), Magic Leap (Magic Leap, 2018) and Meta 2 (Prasuethsut, 2016a). These devices allow the user to interact with the two realms performing interactions and receiving real-time feedback.

AR displays are classified by Van Krevelen and Poelman (2010) into three categories: head-worn, hand-held and spatial, based on their positions between the viewer and the real environment. Firstly, head-worn devices consist of 3 types: video and optical see-through displays (HMD), head-mounted projective displays (HMPD) and virtual retina displays (VRD). Secondly, hand-held AR displays consist of hand-held video, optical see-through displays and hand-held projectors

(Slijepcevic, 2013). A number of companies recently started to invest more money in developing products that make use of AR technology; an example is the expected Apple AR smart glasses (Statt, 2018).

AR has many applications in different domains and can enhance the user experience, such as in advertising and commercial services, medical visualization, education and entertainment, military training, manufacturing and tourism. Thus, MR is expected to be more advanced and with more capable technology, it could dominate in the aforementioned fields.

One of the potential applications of MR is in the tourism industry, where it could be used as a tool for tourist guidance and education. AR contributes to the tourism industry in several ways. For instance, it generates a new form of virtual tourism, which converts cyberspace to real space (Kaplan, 2013). Tourism has a greater potential to acquire real benefits from utilising MR technology because tourism is considered one of the most productive economic activities in the world (Side et al., 2014). The main purpose of this research is to introduce the MR technology to visitors in museums in order to facilitate a more immersive and entertaining experience, and enable people to retain more information regarding the exhibits and further to feel a sense of immersion in the heritage.

Introducing MR in the museology and cultural heritage field will be beneficial especially for younger generations who use the internet, smartphones and tablets extensively, and prefer using them in museum visits (Jevremovic and Petrovski, 2012). According to Side et al. (2014), activities such as navigation between different zones inside the museum, reconstructing historical buildings or gaining the experience of three-dimensional models in an interactive manner could be performed by MR application users. These activities will influence the tourist experience worldwide and will reflect on tourism development as well (Dieck et al., 2015).

1.2 Challenges facing the Cairo Museum

Egypt has a glorious heritage of more than 30 centuries from around 3100 B.C. to its conquest by Alexander the Great in 332 B.C. Ancient Egypt was the preeminent civilization in the Mediterranean world (Staff, 2009). Subsequently, Egypt has a significant legacy of monuments and historical sites that attract tourists from all over the world.

The Egyptian Museum in Cairo is one of the most important museums in the world, containing 120,000 antiques consisting of mummies, sarcophaguses, pottery, jewellery and King Tutankhamen's treasures. It has many sections, which are arranged in chronological order, beginning with the famous Tutankhamun's treasures. The second section houses the pre-dynasty and the Old Kingdom monuments. The third section contains the first intermediate period and the Middle Kingdom antiques and monuments passing to the fourth section which houses the monuments of the Modern Kingdom and then the monuments of the late period and the Greek and Roman periods in the fifth section. The sixth section contains papyrus, coins and finally, the seventh section contains old Egyptian sarcophaguses (Egypt, 2014). More than 1.5 million tourists from all over the world and half a million Egyptians visit the museum annually (Egypt, 2011).

Although tourism in Egypt is a significant integral part of Egyptian society and one of the most important sectors in Egypt's economy, during the last few years tourism in Egypt has experienced a dramatic decline. Egypt started to lose international arrivals following the revolution of the 25th of January 2011, known as the Arab Spring, which occurred in the Middle East. The number of visitors to the Egyptian Museum in Cairo subsequently dropped from 14.7 million to 5.4 million (Economics, 2015).

To tackle this significant problem, the Egyptian government has announced short-term plans to invest and run campaigns for promoting tourism and restore confidence with a potential increase in the count of tourist arrivals (News, October 28, 2015, Mintle.com, Feb 2014).

This research project aims to find a practical solution, particularly for the museum under study. The solution is expected to encourage visitors to come to the targeted museum and to attract visitors internationally. A number of exploratory studies were conducted in the research to identify problems that might negatively influence the museum experience and provide solutions to attract more visitors.

1.2.1 Museum Visit Average Duration

Based on a prior interview with one of the Cairo museum's curators, it was stated that either national or international museum visitors usually spend an average one hour in the museum, including roaming and touring. Based on the nature of the museum and its number of collections and rooms, this phenomenon was unusual as it also contradicts other studies that report that the average time spent in museums varies between 120 and 180 minutes (Chia et al., 2016), and between 90 and 240 minutes in the Louvre museum (Yoshimura et al., 2016). Many factors, can influence the time spent in museums such as economic, psychological, socio-demographic, trip-related factors (Brida et al., 2017), entry time, exhibits and number of visitors (Yoshimura et al., 2016). This research focuses on the time spent in front of the exhibited antiques and investigates how the visual experience and information was retained during the tour.

1.2.2 Museum Guiding Manners

The traditional method of guidance, which is usually conducted by human tour guides for several visitors from different nationalities, is the only method of guidance available in the targeted museum. A diversity of guiding methods is considered an advantage for museums, as it provides choices for visitors to choose the most convenient methods of touring; this can reflectively enhance the museum experience (Chang, 2006). Moreover, defining a customised touring route according to what visitors prefer is not provided due to the limited signposting in the museum of study. The most crucial point in this research is that, until now, the workaday performs of guided tours have been unexplored in terms of efficiency and satisfaction. However, there is only one study that articulated the lack of tour guiding guidelines and standards (Doyon, 2008).

1.2.3 Lack of Information Signposted

At the same time, the Egyptian Museum in Cairo lacks critical information for each antique. In fact, not all of these antiques are labelled with tags containing sufficient information and some do not have titles at all. This issue might correlate with the short time spent by the visitors.

1.2.4 Presentation of Information for Visitors

However, there is no easy facility to derive sufficient information about antiques. Apart from the tour guide activities, the only way to obtain supplemental information about the antiques is to look up in the paper-based archive available in a particular room inside the museum. This room is specialised in organising archives that contain all the information about the exhibited antiques. It lacks visual communication of the artefact. As Sylaiou et al. (2008) states, the tourist needs assistance in constructing the meaning of the items exhibited and establish a correlation between themselves, the artefacts and the layers of information about the context.

1.3 Research Scope

This study attempts to tackle the stated problems by conducting an inclusive literature review of guides in museums and potential solutions to improving museum visitors' experience. The literature review identifies a form of guidance that can incorporate MR technology, considering the vital roles of guides that old museum studies emphasised while exploring the real-time reactions and feedback of the workaday routine of the tour guides from visitors of the targeted museum. It also investigates implementing an MR guidance system in order to observe the efficiency of guidance on visitors and enrich the museum with a new exciting interactive guided experience. Moreover, this research aims to demonstrate the impact of MR on the perceived enjoyment, usefulness, and the holistic museum experience, by measuring the engagement and attraction level based on the time spent in the museum before and after the system was employed. As a result, the research seeks to conduct a critical comparison between the guidance conducted by human guides and the guidance with the new MR system introduced.

This research focuses on the Egyptian historical heritage and the use of head-mounted displays, the Microsoft HoloLens in particular, as a guidance and communication tool in museums. Towards this end, methodologies derived from the Human-Computer Interaction (HCI) and Museum Studies fields are combined, in order to achieve the main objective of this study. The present research investigates the change in the human experience when the visitors are exposed to the immersive world which is created by mixed reality. The MR application involves design practices and system developments in particular to boost the level of usability and interactivity.

The new MR guide system incorporates a range of media, such as text, visual and auditory information. This research is keen to reshape the experience of visiting museums, especially the Egyptian cultural heritage, through the medium introduced.

The contribution in this research has a practical side, through designing and developing a mixed reality application that works as a guide tool for visitors and runs through a head-mounted display. On the other hand, the theoretical contribution side is represented by introducing a new form of guidance in museums through a literature review. This new guidance approach was achieved by adopting Design Science Research (DSR) (Hevner and Chatterjee, 2010) as a methodology accompanied with other research methods in order to form a framework to evaluate the guidance approach in terms of the perceived usefulness, usability, interactivity and the willingness of future use.

1.4 Research Questions

1. What is the potential of using mixed reality in the field of touristic guidance at the Egyptian museum in Cairo, if utilised with a combination of visuals, multimedia and human computer interaction techniques?
2. How to design and develop a Mixed Reality (MR) guide system that can adapt the nature of thematic tours and the behaviour patterns of the museum

visitors?

3. What is the potential of using an MR guide system to enhance museum engagement by expanding the time the visitors usually spend?
4. How to evaluate the designed MR guide system in terms of the role of guide and the perceived usefulness, ease of use, multimedia and User Interface (UI), interactivity, and perceived enjoyment.

1.5 Aim and Objectives

This research aims to discover the potential of mixed reality techniques that may be applied to the field of touristic guidance in museums, with a view to enrich and reshape the museum experience by helping visitors to grasp more visual information and perform interactions that can improve the level of museum engagement, which accordingly could expand the time spent in museums.

- ***Research Objective 1***: To investigate the literature review and conduct an exploratory study of the targeted museum towards exploring the optimum guide methods and roles in order to form a new taxonomy of guidance for the proposed system.

- ***Research Objective 2***: To design and develop an application that can be installed on a head-mounted display (Microsoft HoloLens) using MR technology to provide guidance in museum tours via the aid of a personal virtual guide and visual interactive holograms.

- ***Research Objective 3:*** To expand the time spent in front of exhibited items by engaging visitors in storytelling scenes and immersing them in interactive holograms that can motivate them to take part in exploratory activities with the exhibited antiques.

- ***Research Objective 4:*** To develop a framework that can evaluate the MR guide system in terms of the role of the guide, the perceived usefulness, ease of use, multimedia and User Interface (UI), interactivity, perceived enjoyment and the willingness of future use.

1.6 Research Contribution

The contributions of this thesis are focused on the field of Human Computer Interaction, MR applications and also in the discipline of museum studies. In the domain of MR applications, this research introduces the design, development and evaluation of an optimised MR application in a museum context. These are based on the literature review, along with an investigation of the visitors' behaviour patterns at the targeted museum, in terms of the nature of the touring and the guided as well as the unguided tours. Additionally, this study contributes to the theory of the field by introducing a new approach of museum guidance by adopting Design Science Research (DSR) (Hevner and Chatterjee, 2010). This methodology enlightens the researcher to conduct the practical side of this research, which is to design and develop the MR application as a guide tool for visitors, through the use of a head mounted display. DSR is also accompanied by other research methods to form a framework that is able to evaluate the guidance approach in terms of the perceived usefulness, usability, interactivity and the willingness of future use.

This study was conducted in four main phases:

- **Phase 1: Literature of museum guides and the immersive technologies**

A critical literature review was conducted to survey museum guides that use AR and VR technologies, exploring the most recent technologies of AR, VR and MR particularly, in order to identify the most appropriate device for the proposed system. This phase resulted in a new approach of guiding for a new MR guide system, aligned to the essential roles of the guide and functions needed.

- **Phase 2: Qualitative exploration of the museum tours and guide methods**

This phase consists of a combination of observation methods for a group of museum visitors, semi-structured interviews with 9 participants and an in-depth interview with 1 participant. The aim is to explore the museum tours in order to identify the reasons behind the reduced engagement of the visitors, in comparison with the museum guide methods which are provided to obtain a more thorough understanding of the challenges and find a more effective solution.

- **Phase 3: Development of the 'MuseumEye' - the MR museum guide for the Egyptian Museum in Cairo**

By adopting the design science research paradigm, the 'MuseumEye' - the MR system was developed and implemented. This phase was fed by the previous two in order to build a customised guide for the targeted museum's visitors.

- **Phase 4: Constructing a theoretical framework to evaluate MuseumEye using a quantitative data collection method.**

A total of 171 museum visitors and 9 experts in museum studies, HCI and immersive technology completed questionnaires to evaluate MuseumEye. As the participant evaluation was built to measure the role of guide, enjoyment, usefulness, ease of use, multimedia and UI, interactivity and the willingness of future use. On the other side, the expert evaluation was built to measure the role of the guide, tour design, usefulness, content validity, ease of use, multimedia and UI, and interactivity. Also, the evaluation of MuseumEye included a qualitative method by employing an observation of 51 participants to evaluate the system in terms of its engagement level. The outcomes of the evaluation were produced by comparing the observation results before using MuseumEye - in the exploratory study - and during using it.

1.7 Significance of this research

This research adds to the snowballing body of evidence that MR technology can reshape and change the museum visitor's experience. It can influence the three components of museum experience (Falk and Dierking, 2016), which include the personal context, the sociocultural context, and the physical context. This study also provides a new approach that can embrace the essential roles of guides that older studies clarified (Cohen, 1985); (Holloway, 1981), while adopting the design science research paradigm in order to develop a novel MR guide system. Moreover, this study developed a framework for evaluating the MR system to measure the perceived guidance according to the essential roles of the guides, as well as other relevant aspects of the museum experience, such as usefulness and enjoyment, ease of use, interactivity, multimedia and UI, and the willingness of future use.

As a final significant contribution, this study provides a solution for expanding the time spent in museum exhibitions overcoming existing challenges.

1.8 Thesis Outline

The thesis is structured as follows:

Chapter 2 presents a literature review, which is divided into two sections. The first section discusses the museum guides and the second section discusses the immersive technologies.

Chapter 3 presents an exploratory study conducted at the Egyptian Museum in Cairo using qualitative methods to provide more insights about the guided methods in the museums and understand the nature of tours, as well as the visitors' behavioural patterns.

Chapter 4 presents the methodology of the 'MuseumEye' MR system development and the evaluation process.

Chapter 5 presents the design and the development of the 'MuseumEye' system, its functionalities and how it works in a particular room in the museum.

Chapter 6 reports on the evaluation results including the qualitative and quantitative methods, analysis and the discussion. This chapter ends with a critical comparison between the 'MuseumEye' and the human guides.

Chapter 7 concludes the thesis with a summary of the research findings, limitations and future work.

Chapter 2:
Mixed Reality and Guidance in Museums

2.1 Introduction

This chapter discusses the characteristics of Mixed Reality (MR) in relation to other similar technologies such as Virtual Reality (VR) and Augmented Reality (AR). Various MR devices that use different tracking and display technologies are reviewed. Additionally, the chapter demonstrates AR and MR in terms of the current and historical mechanisms, platforms and potential techniques that are suitable for museum guidance. This way, this chapter manifests the rationale underpinning the choice of MR as the preferable tool for the Egyptian Museum in Cairo. Another part of this chapter investigates the guide roles and methods that have been adopted by immersive technology studies. Finally, a new MR guide taxonomy accommodating all necessary technological functions and guidance concepts is introduced.

2.2 Augmented Reality (AR) and Mixed Reality (MR)

According to Azuma (1997), AR is considered one form of MR. However, following recent advancements, AR is now seen as *"a medium in which information is added* *to the physical world in registration with the world"* (Craig, 2013). AR is not limited to displaying visuals by sight only, it also expands to the display of virtual content that is accessible to all human senses (Azuma et al., 2001). It is believed that the idea of inventing this technology came about because of the need to alter and improve the surrounding physical realm (Craig, 2013). It aims to ease people's lives and enhance the perception of and interaction with the real world (Furht, 2011). AR as computer technology has the ability to merge two different worlds – virtual and physical worlds - by giving a continuous feed of multimedia information to conceive, hear, sense, and alter the surrounding environment (Henrysson, 2007).

The first fully functional optical see-through head-mounted display, worked via AR technology and was built by Sutherland in 1968 (Furht, 2011). It was a mechanical set attached from the ceiling to the head of the viewer to display three-dimensional images which changed while the viewer moved (see Figure 2.1) (Sutherland, 1968). This set could mix the display of physical objects with a registry of virtual objects. Since then, the computer graphics industry started to emerge in parallel with the development of tracking technologies – this is discussed in section 2.3.1 (Höllerer and Feiner, 2004), which resulted in applications in domains such as tourism, navigation, military, entertainment and education.

2.2.1 Definition of AR

Historically, the term AR has been broad and not definite, due to its usage in different applications. For example, it has been used to describe any technology that uses glasses to display visuals or any application that can overlay text on a scene (Craig, 2013). Interestingly, the term started to be defined more accurately when Azuma (1997) described AR in his survey as 'a variation of Virtual Environment (VE)', whereby the virtual environment is considered any complete synthetic environment that can immerse a user within it (Azuma, 1997). Whereas, Furht defined AR as 'a real-time direct or indirect view of a physical real-world environment that has been enhanced/augmented by adding virtual computer-generated information on it' (Furht, 2011). Moreover, some definitions seemed to be restricted to particular hardware, such as defining AR as 'a form of VR where the participant's head-mounted display is transparent, allowing a clear view of the real world' (Milgram et al., 1994).

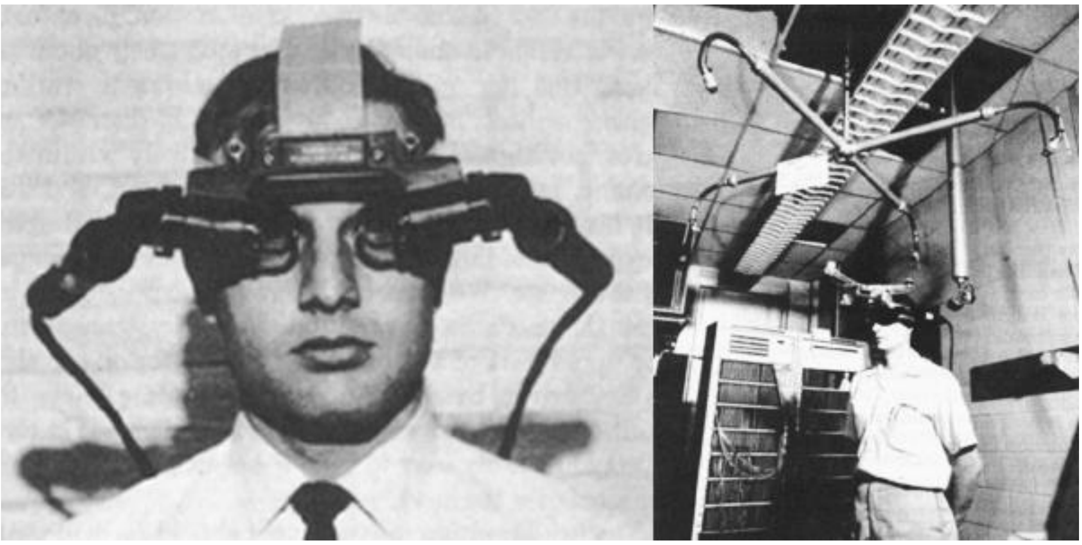

Figure 2.1 Optical see-through head-mounted display by Sutherland (Sutherland, 1968)

2.2.2 Mixed Reality and the 'Reality-Virtuality Continuum'

As explained above, AR and VR were not precisely determined until a broader term emerged, called MR by Milgram et al. (1994). MR is an inclusive term that can embrace the two different worlds: the virtual world and the real world, which differ in their nature. Milgram et al. (1994) developed a continuum (see Figure 2.2) that can differentiate AR and VR and other terms in between. The 'reality' represents real objects in real life, regardless of the way we can see them, through a medium or not. The 'virtuality' represents the synthetic world, generated by computer graphics, which simulate the real world. Between these two aforementioned realities, there is a mixture of different levels. Henrysson (2007) interpreted Milgram's continuum as a range of interaction styles between the human and the computer. He believed that AR occurs when a human can interact with reality, combined with a virtual layer of computer graphics, which function as a medium in-between. In other words, AR could be described as 'hybrid presentations that overlay computer-generated imagery on top of the real scenes'

(Cohen et al., 1993). Augmented Virtuality (AV), which is closer to the Virtual Environment (VE) is described as a virtual synthetic world dominating the scene around the human, whereby a small part of the real world is incorporated.

Figure 2.3 shows an illustration of how AR and AV are different. A good example of AV was introduced by Steinicke et al. (2009) though an immersive virtual environment using a Head Mounted Display (HMD) which can involve realistic visuals of the same scene. Another demonstration of AV was formed by Regenbrecht et al. (2003) through a technique that can immerse personnel in a virtual conference room. Indeed, many applications adopted AV for their purposes such as the new method developed by Paul et al. (2005) for viewing 3D scenes of neurosurgery operations through binoculars.

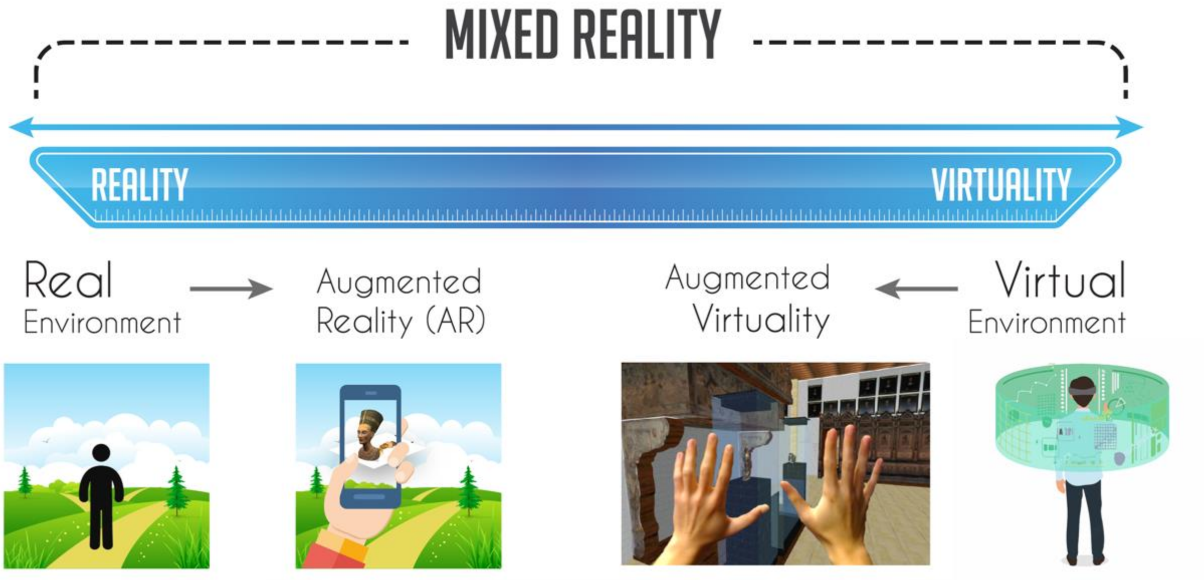

Figure 2.2 Reality-Virtuality Continuum (Milgram et al., 1994). Image of augmented virtuality source (Steinicke et al., 2009).

2.2.3 Augmented Reality and Mixed Reality

Azuma et al. (2001) state three principles to identify if the technique is AR:

- It integrates real and virtual objects in the real environment.

- It is interactive and runs in real time.

- The virtual objects are registered in the real world.

AR is not limited to vision, it can be extended to communicate with other human senses such as hearing, touching, and smelling. AR can occupy an intermediate layer between the human and the virtual, acting as an interactive component between them, aligned with the real world (Henrysson, 2007). In addition, AR is not limited by any particular hardware, it is a wide concept that can include any hardware, which can combine virtual objects with real ones (Azuma, 1997). Devices that have the ability to embrace AR could be optical see-through (OST) HMD, video see-through (VST) HMDs, monocular systems, projection-based displays and monitor-based interfaces.

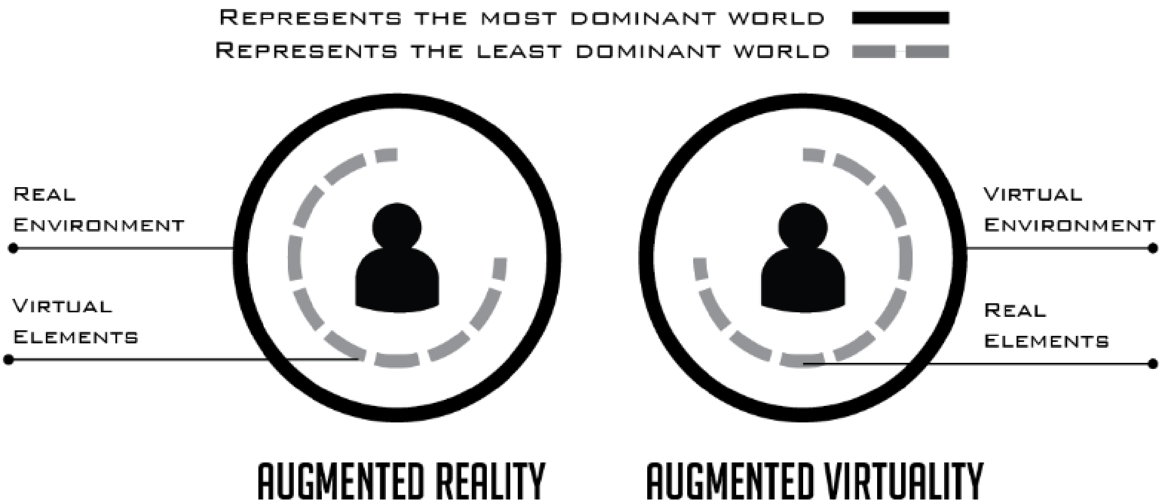

Figure 2.3 Augmented Reality and Augmented Virtuality from the perspective of the dominant world in the actual scene

MR is a broader concept that can embrace AR and AV, which are two technologies that can merge the virtual and the real world as Milgram et al. (1994) demonstrated in the virtuality continuum. Milgram et al. (1994) sought to find a proper taxonomy for MR through certain devices after dividing them into classes. These classes differ in relation to whether the primary world is real or virtual, the real objects are observed directly or indirectly. To formalise the taxonomy of MR, Milgram et al. (1994) addressed the following three questions:

- How much does the observer know about the displayed world?

- To what degree is the scenery realistic?

- To what extent is the observer immersed by the illusion of the combination of the virtual and the real world?

However, another approach introduced by Ma et al. (2015) argues that MR is relevant to the time of displaying visuals, since displaying the pre-made virtual objects and physical reality are presented in the real-time with a seamless transition between them and can be defined as MR (Ma et al., 2015).

2.2.4 Mixed Reality – New Taxonomy

Following the new emerged technologies that expanded on the inclusion of both the virtual and the physical environment in a wide manner, Bray (2018) proposed a new taxonomy of MR, as depicted in Figure 2.4. The technology present in immersive and holographic devices expanded their range in the Milligram MR continuum. This expansion is made possible thanks to advancements of the sensors, the ability to allocate users in the two realms together and the ability to understand the characteristics of the physical environment with technologies such as spatial mapping. These technologies are capable of minimising the space between the physical and virtual environments and enhance their integration. Thus, the MR, in this case is not just a continuum, it is a new approach of technology that is employed and utilised by emerging devices such as Holographic and Immersive technologies.

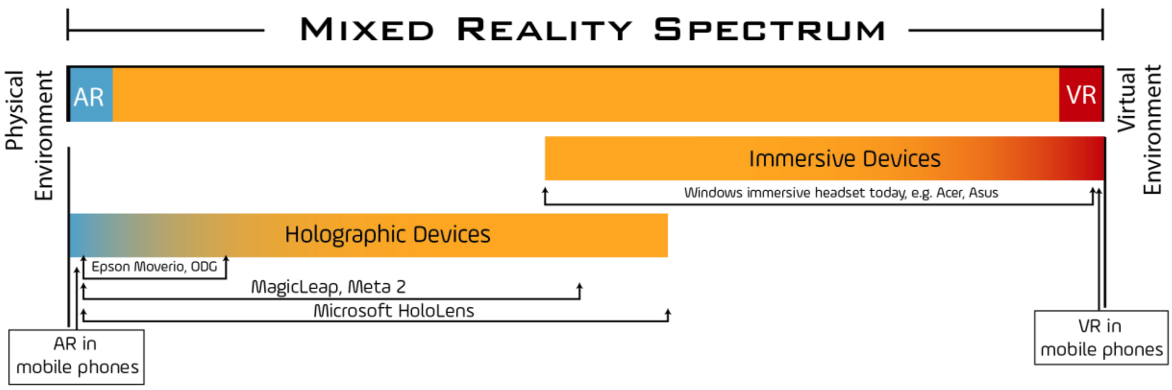

Figure 2.4 Mixed Reality Spectrum concept developed from Bray (2018) and the allocation of holographic and immersive devices

Holographic devices, such as Microsoft HoloLens (Microsoft, 2015b), Magic Leap (Magic Leap, 2018) and Meta 2 (Prasuethsut, 2016a), have the ability to allocate the virtual content in the physical environment as if they really exist (Bray, 2018). The immersive devices, on the other hand, have the ability to construct a sense of presence by hiding the physical environment and replacing it with virtual content (Bray, 2018). Examples of these devices include the Acer headset (Warren, 2018), ASUS headset (Allison, 2018), and Dell Visor (Atkinson, 2018).

AR and MR are interchangeable terms, especially when studies involve holograms observed by Microsoft HoloLens. For instance, AR was used as a term in studies that utilised Microsoft HoloLens (Hockett and Ingleby, 2016). However, MR was also used in other studies that utilised the same device (Kress and Cummings, 2017); (Hurter and McDuff, 2017). The researcher chose MR, as it represents the technology and its capabilities compared to AR. MR – as an advanced form of AR technology - has more potential due to the capability of immersion, human-environment interactions, and an understanding of the surrounding environment, more than the normal AR applications that currently can do. Microsoft, as a leading company in MR HMDs, defined HoloLens as an MR holographic device, so it was wise to follow the same definition and terminology.

Positioning MuseumEye – the MR application- in the MR continuum is shown in figure 2.5 and it also shows the capability of its functions in the spectrum of holographic devices in particular.

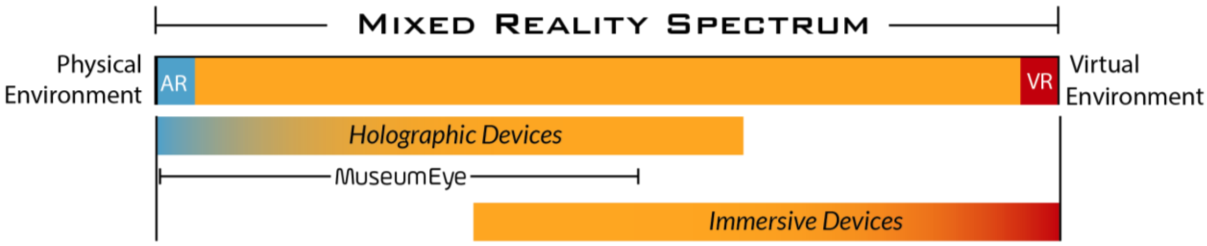

Figure 2.5 MuseumEye position in the Mixed Reality Spectrum concept by (Bray, 2018)

2.3 Techniques, Hardware and Software

This section introduces different tracking techniques, devices and headsets that can be used with AR technology, alongside relevant platforms, software, and SDKs.

2.3.1 Tracking Techniques

Tracking is the fundamental technology that enables AR functionalities in a system and can be classified into visual-based, sensor-based or hybrid.

- Visual-based Tracking Technique

This technique uses image processing methods in order to calculate the position of the camera relevant to the objects of the real world (Zhou et al., 2008a) and it has the ability to constantly correct it (Bajura and Neumann, 1995). Wuest et al. (2005) explain that this method finds correspondence between the features of the 2D images and the relevant 3D coordinates in the 3D world.

Pressigout and Marchand (2006) believed that visual tracking techniques – or vision tracking - could be divided into feature-based and model-based. Others define feature-based as marker-based tracking (Wagner et al., 2008), because they track 2D features such as primitive geometrics (Shi, 1994) or object contours (Isard and Blake, 1996) or barcodes, in order to enhance the registration in the 3D world (Rekimoto, 1998). Later, these techniques extended to include natural features beyond their synthetic ones (Park et al., 1998) and LEDs (Naimark and Foxlin, 2005). This method has been proven to be efficient in applications for museums (Rekimoto, 1998, Rekimoto and Ayatsuka, 2000, Wojciechowski et al., 2004, Damala et al., 2007, Damala et al., 2008), though it may suffer from low accuracy and may present illumination problems (Pressigout and Marchand, 2006).

The second method of visual-based tracking is model-based tracking, which normally relies on features such as lines or special edges in the real model (Zhou et al., 2008b). Fua and Lepetit (2007) developed this method by tracking gradient features in the actual model. Others developed real-time model-based tracking with the ability for adaptive learning along the process in order to enhance the robustness and continuity of the tracking (Wuest et al., 2005). Then, some developments occurred to include combining textured 3D model-based tracking with the detection of edge features (Reitmayr and Drummond, 2006).

These visual techniques are adopted particularly in mobile and smart glasses/

HMD devices, such as Simultaneous Localisation And Mapping (SLAM), markerless tracking, or spatial mapping. SLAM is the process of creating the 3D edge model from a sequence of images in real-time without acquiring information from the existing world before the tracking process (Neubert et al., 2007). SLAM systems are frequently used to point features in the 3D model as landmarks to be tracked. Davison (2003) developed a SLAM technique, working in real-time by tracking natural features using motion modelling with a hand-waved camera. Others introduced a distinguished SLAM framework that can improve the estimation of the camera movements by detecting gradient-based images (Molton et al., 2004). Klein and Murray (2007) introduced a method for tracking a hand-held camera in order to produce highly detailed maps of thousands of landmarks in real-time. New solutions enabled recovering frequent errors in order to achieve higher performance (Chekhlov et al., 2006). It is worth mentioning that both mobile and some HMDs such as Microsoft HoloLens (Selleck et al., 2018) are using SLAM technology to support augmentation functionalities.

Teichrieb et al. (2007) explain Markerless Augmented Reality (MAR) as the integration of 3D virtual objects with the real world, in real-time. There is a major difference between marker-based and markerless techniques. The former uses traditional fiducial markers to recognise the position and the orientation and the latter considers any part of reality a marker in order to place a virtual object on it. This method has helped overcome tracking problems, such as occlusion, illumination and mistracking (Comport et al., 2006). Furthermore, it can enhance user perception and interaction with the real world (Teichrieb et al., 2007). MAR tracking could be integrated with a particular sensor or multisensory system in order to allocate virtual objects in the real environment, for example, GPS triggering, hybrid vision, gyroscope, or infrared triggers (Proctor, 2005); (Azuma, 1997); (Azuma et al., 2001), but also with the use of monocular (Barandiaran et al., 2010, Davison, 2003) and Kinect cameras (Newcombe et al., 2011). MAR tracking has been used in many applications in the field of museology, for example, the 'MapLens' project (Morrison et al., 2009), the 'ANR GAME' project (Tillon et al., 2010) and other heritage applications (Damala and Stojanovic, 2012).

Spatial Mapping is featured in some recent HMDs such as Microsoft HoloLens. It is a process of capturing the surrounding physical environment by photoelectric sensors and converting it into spatial information (Selleck et al., 2018). Spatial mapping can deliver a detailed representation of the physical environment around the user who wears the headset (Zeller et al., 2018a). Using the captured spatial information, the headset is able to generate a detailed 3D representation of the physical environment (Selleck et al., 2018). A better understanding of the real world surfaces means better integration with the virtual world and more interactions between the user and both realms (Zeller et al., 2018a).

- Sensor Tracking Technique

Sensor tracking techniques rely on different types of sensors such as magnetic, inertial, acoustic, mechanical, or optical sensors.

Bluetooth is one of the technologies used to provide location awareness features. Bluetooth could be a proper choice, especially for impaired visitors because the triggering method does not need line-of-sight (Damala, 2009). However, Bluetooth is not feasible most of the time due to the delay of transferring files to the user's device from the source of the multimedia content. It might take approximately 10 seconds to transfer merely 1mb of video or audio file (Proctor, 2005). Designing tours should take into account the valuable time of the visitor and the number of locations that the visitor desires to visit. Therefore, Bluetooth is not suitable for transferring virtual content but has advantages such as low-power consumption and the ability to connect with eight devices simultaneously in a range of 10 meters (Georgakakis et al., 2010).

RFID tags have been utilised in museums to allow visitors to bookmark MP3 players at the Peabody Essex Museum in Massachusetts and Museum of Kunsthistorisches in Vienna (Proctor, 2005). Another experiment used RFID to read tags by smartphones and play narrations of the exhibited items in the Conservatoire National des Arts et Métiers museum in France (Merdassi et al., 2007).

- Hybrid Tracking Technique

Tracking techniques can also be combined together to achieve more precise results, for example, image processing and DGPS (Vlahakis et al., 2002), RFID with markerless tracking (Miyashita et al., 2008), and visual tracking with GPS (Morrison et al., 2009).

2.3.2 Hardware

AR displays have been classified by Van Krevelen and Poelman (2010) into three categories: head-mounted, hand-held and spatial, based on their positions between the viewer and the real environment.

- Hand-Held Devices

Many scholars (Kato and Kato, 2011); (Slijepcevic, 2013); (Yovcheva, 2015); (Weng et al., 2013) state that hand-held devices, such as smartphones are excellent tools for introducing AR commercially. Additionally, they offer a cost-effective way to use AR systems compared to data gloves or 3D pointing devices (Weng et al., 2013). Smartphones are a tool for enhancing people's cognition and helping them interact with an unfamiliar urban environment (Yovcheva, 2015).

- Head-Mounted Displays (HMDs)

Some see-through HMDs are utilised to make the user see the world mixed with virtual objects and physical ones. In this case, the virtual objects are superimposed on the physical objects via either optical or video technologies. They can be divided into 2 categories: optical see-through (OST) and video see-through (VST).

OST makes the user see virtual objects superimposed and blended with the real world with their eyes, along with a holographic optical layer. In other words, graphics are superimposed on the real environment through additive mixing. Thus, the graphical areas are drawn as black, but they appear as transparent to the user, in order to achieve the blending (Klopschitz et al., 2010).

One positive feature of the OST HMD is the ability to produce a neutral, instantaneous view of the real world with a remarkable result. The real world has an unmodified scene, so the real objects are seen in high resolution and without any delay (Zhou et al., 2008b). However, OST does have a disadvantage, which is its poor integration between the virtual objects and the real world. The reason is that the computer of the HMD cannot identify the gaze point and the focus of the user (Klopschitz et al., 2010).

The second category of HMDs is the VST, which works by overlaying graphics on a video view of the real world (Zhou et al., 2008b). In other words, the view of the real world is streamed in a live video from the HMD's camera. Then, the graphics augmentations are presented in that video feed by blending them with the real world scene (Klopschitz et al., 2010). One positive feature of the VST is that overcomes the occlusion problems better than OST HMDs. Moreover, VST has various image processing techniques such as adjusting and correcting the intensity, along with blending the ratio control and tint (Kiyokawa, 2008).

<u>HMD devices currently on the market</u>

With the advancement of headsets that incorporate AR and MR technologies, a considerable number of companies started to invest in building HMDs and smart glasses such as the Google glass project (Sood, 2012). Then, a set of HMDs with outstanding potential were released (at the time of the research), such as Epson Moverio smart glasses (Epson, 2015), Magic Leap (Magic Leap, 2018), ODG – R7 AR smart glasses (Prasuethsut, 2016b), Meta 2 Glasses (Prasuethsut, 2016a), and Microsoft HoloLens (Microsoft, 2015a) (see Figure 2.6). A critical comparison of these devices in terms of the hardware and software specifications are detailed in Appendix A.

Rationale of the Hardware Chosen

- Human factor: Based on the nature of using hand-held devices during particular activities, such as touring in museums, the visitors who are going to use the AR guide should keep lifting their arms and pointing the rear cameras to the spot they want the augmentation to be generated. Considering the time of visits, which could take a couple of hours or more, the visitors might not keep lifting their arms along the entire visit due to fatigue. However, by wearing the HMD, the user does not have to keep lifting their arms all the time, except for minimal arm and hand gestures.

- Usability factor: mobile device users have to use one hand, and have one free hand, while the HMD users can have two hands free.
- Interactivity factor: like the previous point, mobile users have limited space for interaction, since they have to interact with the augmentations through mobile with small screens. While the HMD users, on the other hand, have a wide space around them to perform interactions.
- Immersion: HMDs are more immersive than mobile devices (Wagner, 2007a) since the HMDs' augmentations are spherically presented around the user.

Figure 2.6 Potential HMDs currently in the market - Source: A-(Magic Leap, 2018), B - (Prasuethsut, 2016b), C - (Epson, 2015) , D- (Prasuethsut, 2016a), E - (Microsoft, 2015a)

These head mounted displays were one of the choices that might be adopted for this research. Despite their potential in AR/MR technology, the researcher chose to use a Microsoft HoloLens that embraces the project due to its specifications and abilities. Appendix A shows a comparison of the most recent MR devices on the market according to their specifications. Certain criteria prioritised the choice of device, such as the need for performing long visits, being lightweight, human ergonomics standards.

2.3.3 Software

There are many software development kits (SDKs) already in the market, which are essential for building AR/MR applications, either on smartphones or smart glasses/HMDs. Most of them require a game engine, such as Unity3D, to deploy the application on devices.

- Vuforia is the most famous platform in the field of AR mobile applications. It can support Unity3D, Android, iOS and Windows. Vuforia supports two different types of visual tracking: marker-based tracking and markerless tracking. VuMark is a marker-based tracking which is a combination between a QR-code and an image. Regarding markerless tracking, Vuforia supports the recognition of basic 3D objects such as a box, sphere or plan (Vuforia, 2016).
- ARToolKit is an open source tracking library for AR platforms. It can support Android, iOS, Windows, Mac OS and Linux. ARToolKit can support marker-based tracking as the fiducial markers but it does not support markerless tracking (ARToolKit, 2016).
- Wikitude SDK is one of the leading SDKs in AR mobile applications and it has similar advantages to Vuforia. It supports a wide range of platforms, such as Android, iOS, and some smart glasses' platforms. It can support marker and markerless tracking, either 3D tracking or SLAM-based. Wikitude has outstanding potential due to the features of extended tracking and cloud recognition (Wikitude, 2016).
- Kudan is the first SDK that provided markerless tracking. It supports marker-based tracking as well but its strength against the rest of SDKs is the efficiency of placing 3D objects in the 3D world without a marker and very accurate (Kudan, 2016). Despite these qualities, it has a drawback which the researcher experienced. The application deployed by the Kudan SDK might be susceptible to crashes.
- ARCore is an SDK for the Android platform for Google, which is capable of understanding the real world and make the user interact with the virtual information. ARCore relies on three capabilities: motion tracking,

environmental understanding and light estimation (Google, 2018).

- ARKit is an SDK for the iOS platform. By using the iOS device's camera, gyroscope, accelerometers, and context awareness, it can create environmental mapping as long as the device moves (Apple, 2018).
- HoloToolKit is a set of scripts that aids the developers of Microsoft HoloLens to build immersive MR applications. It is employed in the development process by adding them to Unity 3D with the presence of Windows 10 as the managing operating system for the process (Cosmos, 2018).

Only Vuforia and HoloToolKit supported HoloLens development, however, HoloToolKit was chosen for development, as it provides all necessary scripts for the required functions for the MuseumEye system.

2.4 Guidance in Museums

The most prominent and persistent roles that museums play are in attracting people and enriching their knowledge (Doering and Pekarik, 1996). Consequently, museums incorporate diverse practical activities that can engage the public. One of these activities is tour guiding. Guidance could be defined as verbal or non-verbal instructions and information that can help visitors in museums (Fine and Speer, 1985). However, tour guidance as a practical activity is an organized scenario that has the ability to engage, amuse, educate and feed the visitor with required information in a sensible path in the museum. Moreover, it is considered an outstanding and enduring feature of the museum visitor programme (Best, 2012).

There are many studies that have focused on visitors of museums and the aspects of communication and interactions that take place (Hooper-Greenhill, 2013, Yalowitz and Bronnenkant, 2009, Hodge et al., 1979, Duffy, 1989). These studies reveal the main features of guided tours, which are described as a set of interactive actions and mechanisms that the guide can follow to foster the audiences' contributions and engagements. In addition, they also imply that guide tours are not like a lecture given as a monologue performed by someone. The guide represented in these studies includes the human guide as well as the digi-guides.

Many studies have been conducted to emphasize the actual role of the tour guide and how they educate visitors (Hooper-Greenhill, 1999, Pond, 1993, Horn, 1980, Mancini, 2000). For instance, Cohen (1985) emphasised the most prominent roles that the modern tour guide must fulfil. The first role is that of 'pathfinder', which leads visitors around the museum through a pre-planned route (Cohen, 1985). The second role is that of 'mentor', which provides information for visitors about the site (Cohen, 1985). Additionally, museum mentoring involves social interaction in face-to-face settings (Goodwin, 2007) practising guidance with visitors as Best (2012) described: 'For example, guides use pointing, or their own gazing at objects, as the group move to orient themselves and others to new foci'. Thus, the mentoring role involves being a 'social mediation' and 'cultural brokerage' (Holloway, 1981, Cohen, 1985). There are some other guide roles such as 'actor', 'information-giver', 'ambassador', 'catalyst' (Holloway, 1981), 'leader' (Cohen, 1985), 'teacher', 'caretaker' (Fine and Speer, 1985), 'interpreter/translator' (Almagor, 1985), and 'organiser' (Hughes, 1991).

Many methods have been created to assist the museum visitors' navigation inside the different sectors and halls and to guide and provide them with the information they needed (see Figure 2.7). However, they all vary in their method of delivering information about the exhibits and their locations inside. Unfortunately, these methods have some limitations in supporting the visitor straight away. This section will explore the current guided methods used in museums. Moreover, it will demonstrate limitations regarding visualisation, mobility, guidance roles and others.

2.4.1 Human Guide

Human guidance is the most popular guiding method in museums and has both positive and negative aspects. The positives are several, for instance, this method provides the ability to pick clues from audiences during the visit. Furthermore, utilising where the audiences' gaze on the exhibited item helps orient their gazes for the sake of more engagement (Best, 2012). Human guidance has another outstanding and engaging feature. It can use verbal and non-verbal messages - such as body language- to convey information during the tour (Best, 2012). It could also be preferable in some ways when the museum intends to add a personal touch to information disseminated (Jamison et al., 2002).

This type of guidance also has some negative aspects. Mason and McCarthy (2006) showed that young audiences consider the human guidance method boring and somehow instructional. Younger generations prefer interactivity, which is derived from their evolving educational systems (Best, 2012). Jamison et al. (2002) mention two situations where the human tour guide is not preferable: when the visitor desires to explore certain places, that differ from the tour guide's route, and when the visitor disagrees with the tour guide's bias in terms of their contextual interpretations. Furthermore, one scholar claims that human guidance cannot maintain a consistent level of performance (McLoughlin et al., 2007). Another reason for not preferring a human guide is if the person desires to see specific venues in the museum or when the information presented is different than the tour guide's (Jamison et al., 2002). For these reasons, it might be reasonable to replace the human guide with other guide methods. Some scholars claim that human guides might be provided as a service to those who need specialist tours for particular purposes. Whilst standard tours could be operated via Audio guides (McLoughlin et al., 2007) others consider how digital multimedia guides can show an 'On-demand tour guide' (Ghiani et al., 2009, Jamison et al., 2002) that can deliver personalised information for the tour in conjunction with providing information about the objects.

On the other side, the tour guide can receive questions and reply, which represents the most crucial interaction aspect that could be lacking in multimedia digi-guides.

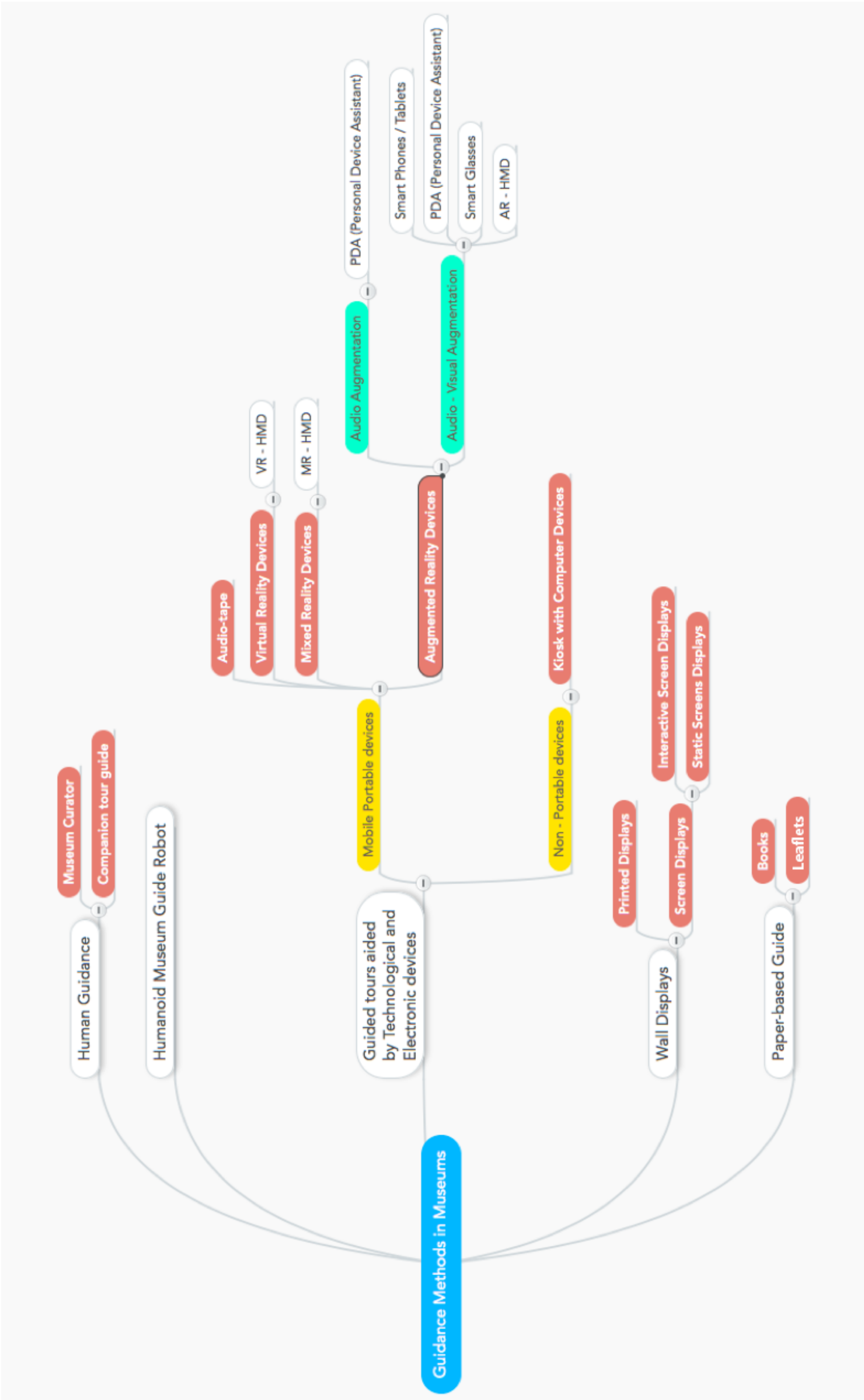

Figure 2.7 Flowchart includes most of the guidance methods applied in museums

2.4.2 Humanoid Robot Guide

A robot-guided tour is one of the methods that could enrich the role of tour guides in museums. The robot guides evolved to be intelligent and act like humans and sometimes they can achieve beyond human limits (Burgard et al., 1999). Robots have been used in many museums in order to assist, educate and entertain visitors. They have the ability to lead visitors to exhibits of interest and provide multimedia presentations at every individual stop (Nourbakhsh et al., 1999). Many scholars (Burgard et al., 1998, Burgard et al., 1999, Nourbakhsh et al., 1999, Thrun et al., 1999b, Nourbakhsh et al., 2003) have shown the independence of the role of robots in museums and how artificial intelligence and robotics can be useful to the field of museology and museum guidance. Furthermore, these robots have proven to have an efficient ability in interacting with humans in a methodical way by recognising the visitors' voices and speaking with them (Clodic et al., 2006). Other studies (Kuno et al., 2007) emphasise 'friendly' human-robot interaction via non-verbal behaviours. It was found that robots can guide people in museums and they could interact with thousands of people (Kuzuoka et al., 2008). As a result, museum attendance increased by more than 50% (Burgard et al., 1999).

Despite the positive outcomes of robot guidance, they also suffer from drawbacks. Robots are expensive and they require regular maintenance, which in turn requires additional costs. Also, robots cannot work independently; they often need human assistance.

2.4.3 Wall Displays

Wall displays include printed posters and electronic displays. Printed posters are used as guided information fixed on museums walls. A study claims that museums need posters containing photographs to assist visitors (Thompson, 2015). These electronic displays include static and interactive displays. Few studies seek to exploit interactive displays as TV-like personalised presentations, dedicated to assisting younger visitors along with their tours in museums (Rocchi et al., 2004, Krüger et al., 2003). Furthermore, Raptis et al. (2005) stated that some designers put interactive devices such as smart tables in museums. However, wall screens that are either printed, static or interactive are not portable and handy to use when visitors explore several sites inside the museums.

2.4.4 Paper-based Guides

Paper-based guides are classified into two main types: guidebooks and catalogues. Museums and cultural heritage sites are conventionally used to provide the content needed for visitors in the forms of text – panels and labels (Xu et al., 2012). Although museums often consider guidebooks or catalogues as efficient methods, some scholars claim that they are too cumbersome to carry during the tour and it could take hours to finish reading the catalogues completely (Sparacino, 2002).

2.4.5 Guided Tours aided by Technological and Electronic Devices

All methods used in the museum that deploy technological and electronic devices are classified as 'non-portable devices' and 'mobile portable devices'.

Non-Portable Devices

Interactive multimodal kiosks have emerged in recent years in museum galleries (Sparacino, 2002). Kiosks provide visitors with information in an intuitive way (Mäkinen et al., 2002). Studies divide kiosks into four categories: informative kiosks, service kiosks, advertising kiosks and entertainment kiosks (Borchers et al., 1995). A service kiosk might be exploited by adding a speech recognition component to assist visitors (Lamel et al., 2002), while the informative kiosks may have a touch-screen computer and friendly interface, which can interact and behave like a human by detecting the facial expression of the user via a webcam (Mäkinen et al., 2002). Also, a stereoscopic technique is utilized in kiosks that are operated by VR kiosks that have limited dimensions and they usually lack immersive features. Some studies claim that kiosks draw visitors to specific exhibit locations (Nourbakhsh et al., 1999). Another drawback highlighted by Sparacino (2002) is that visitors might spend much time exploring the information in the interactive kiosks and people do not have much time to devote it there.

Mobile Portable Devices

Audio-tape guides emerged in the 80s with the use of walkmans, which contained a narration of historical stories and information that users could playback during their visit (Vlahakis et al., 2003). Scholars have highlighted disadvantages, such as the social isolation that this method might cause. The reason behind this is that the visitor might avoid social interaction because if the visitor turned off his device, it was difficult to resynchronise it again (Vlahakis et al., 2003, Kortbek and Grønbæk, 2008).

VR might be one of the most appealing and effective technologies to immerse users in a computational synthetic environment. However, Carrozzino and Bergamasco (2010) assume that it is uncommon to equip museums with immersive installations. In contrast, in archaeological sites, VR found its position in integrating and visualising a set of temporal 3D archaeological data in different times (Zuk et al., 2005). Some studies exploit VR games in museums for educating and entertaining visitors (Lepouras, 2004). Other studies utilise VR technologies in museums to virtually reconstruct the ruined heritage and give a different experience to the visitors on-site (Pujol, 2004). However, VR is an isolating technology when deployed in a museum due to limiting social interaction. For this reason, VR is not considered an ongoing tool that suits the nature of touring.

Audio augmentation, as Bederson (1995b) states, is the process of superimposing audio content based on the location of the visitor. Bederson (1995b) aimed to overcome the drawbacks of taped tours to enhance the richness of the real-world during tours. This project aimed to give visitors random and free access to non-linear tracks via digital devices without isolating visitors from social interactions (Bederson, 1995b). Although this augmentation has proven to be a significant assistance to the visitor, the information conveyed is limited (Sparacino, 2002). Recently, museums have started to implement multimedia mobile tablets that can make visitors capable of using them during his visit. The most well-known example of these devices is that which is currently being used in the British museum in London depicted in Figure 2.8. However, the lack of social isolation still exists (Baker et al., 2017).

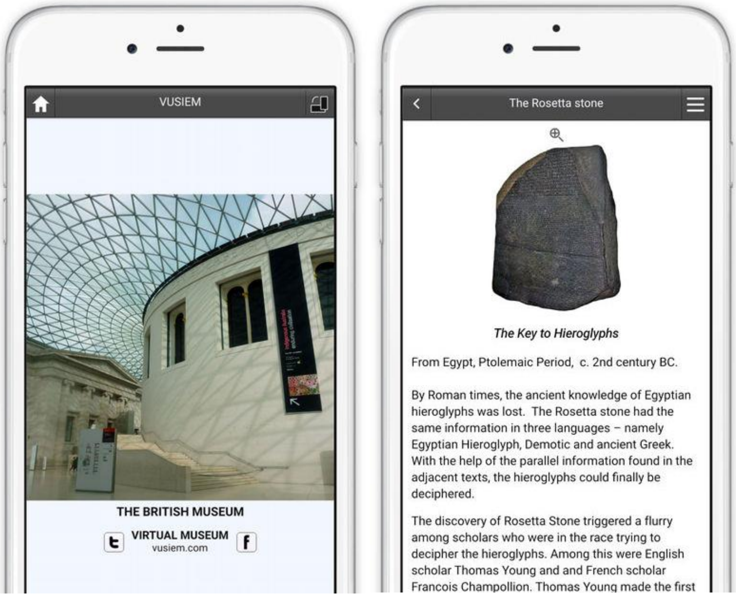

Figure 2.8 Screenshots from the Interface of the British museum mobile guide. (Ltd, 2017)

Researchers (Rekimoto and Ayatsuka, 2000, Sparacino, 2002, Damala et al., 2008, Owen et al., 2005) have attempted to add visuals to audio augmentation in order to enrich the experience of touristic guidance in museums. Some scholars use QR codes as a marker for AR (Jevremovic and Petrovski, 2012).

In the last few years, markerless AR has been involved in the restoration domain of museums (Banterle et al., 2015). Also, the AR experience involves restoring and reconstructing scenes of ancient life in a storytelling manner (Vlahakis et al., 2003). These restorations extended to the outdoor archaeological sites (Kaplan, 2013).

Wearable devices started to replace the desktop computers and showed potential for many applications including the museum domain (Starner et al., 1997). For example, Rekimoto (1998) used a Video See Through Head mounted display (VST-HMD) to scan fiducial markers to trigger the virtual content by the AR technique. Sparacino (2002) used a wearable device, which is operated by a system that can personalize the visitor’s preferences.

Then, Vainstein et al. (2016) conducted a study to explore the potential of Head Worn Devices (HWD) after the elicitation of the visitor's requirements in museums. Recent studies measured the suitability of using Google cardboard for AR museum guides (Theodorakopoulos et al., 2017). Moreover, Google cardboard was used again in an interactive AR guide accompanied by a smartphone (Lee et al., 2017). Moreover, wearable devices could be associated with handheld devices in order to deliver guiding services within museums using AR technology (Serubugo et al., 2017).

The outdoor cultural heritage sites were privileged with AR guidance, such as *'Archeoguides'* (Vlahakis et al., 2002). Similarly, the LIFEPLUS introduced an AR guide via an interactive audio-visual presentation to visitors. However, LIFEPLUS relies on GPS in indoor museums and outdoors sites. It might be appropriate for the outdoors but GPS for indoor locations is still inaccurate (Proctor, 2005). Another study "ARCO" utilized X-VRML visualization templates to display the museum artefacts using AR tools (Wojciechowski et al., 2004). Nevertheless, interactivity with 3D artefacts must be performed in kiosks away from the real exhibits. That's why it is not considered an efficient way to be applied on-site. Moreover, this study did not show how this paradigm facilitates the guidance of tours inside museums in case of considering AR a substitute method of guidance. It is worth mentioning that the AR applications have invaded many natural museums (Baker, 2012, Lovett, 2010, Barry et al., 2012, Currie, 2015).

Researchers have developed an AR guide that is fully functional for guidance with the use of a portable device (Damala et al., 2008). Subsequent studies deployed an AR mobile guide in the Louvre museum's Department of Islamic Art, and were concerned with two functions: guidance and artwork appreciation (Miyashita et al., 2008).

Some AR projects use standard display hardware that has a web camera attached (Edmund Ng Giap et al., 2011). Recently, some scholars have used an AR to overlay historical images from the past on a building as a way to enhance engagement in museums (Javornik et al., 2018). One study employed an interactive AR experience that takes input from hand motions and images in a printed guide (Chen et al., 2014). Another interactive AR experience involved the visitors to change colours of the virtual paintings (Ryffel et al., 2017). Subsequent studies put emphasis on personalizing the storytelling virtual content that is incorporated with physical objects (Pujol et al., 2012, Roussou et al., 2013). Likewise, another study exploited the previous features by overlying information via AR (Keil et al., 2013, Xu et al., 2012).

Figure 2.9 shows the most recent AR applications available in the iTunes and Google Play app stores, designed and developed for museums.

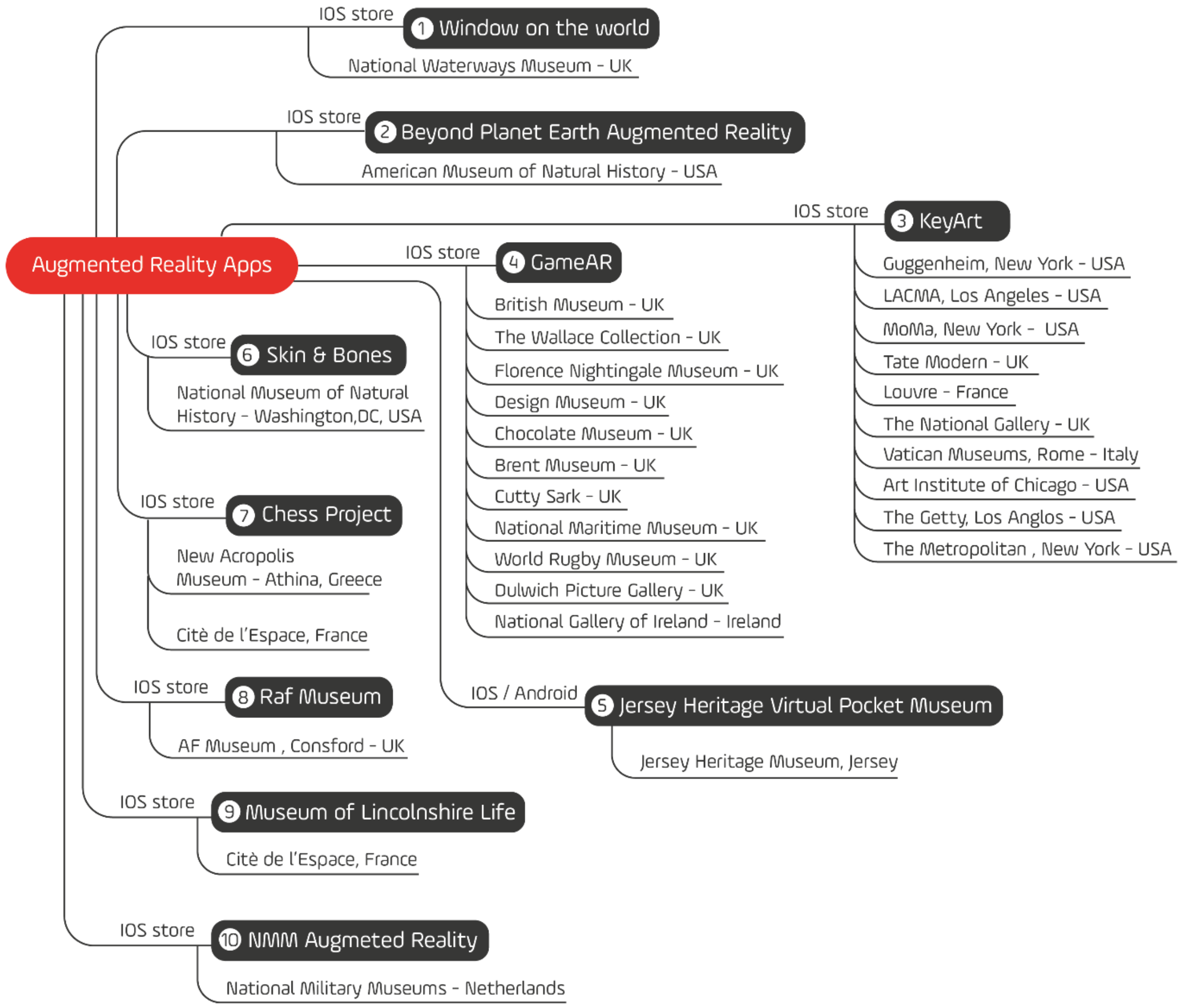

Figure 2.9 AR Apps in the market from IOS / Android Stores

MR has obvious contributions in the museum and cultural heritage sector. One MR project that is able to extend the exhibition space with virtual content, visualises ancient sea life (Hughes et al., 2004). MR was used also to extend the archaeological sites in the 'SHAPE' project in order to enhance the educational and social experience of the visitors (Hall et al., 2001). The 'ARCHEOGUIDE' project has been designed to equip the visitor with a mobile computing unit in a backpack, in addition to a see-through HMD attached with an earphone, as depicted in Figure 2.10 (Vlahakis et al., 2002) using a marker-based tracking technique (Edmund Ng Giap et al., 2011).

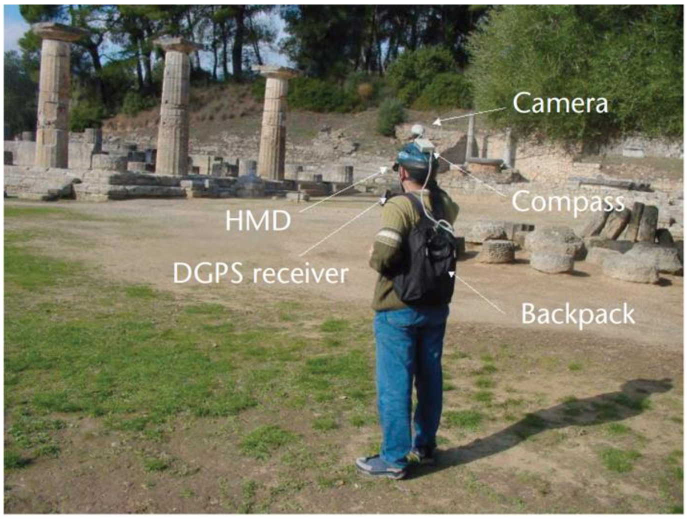

Figure 2.10 Wearable devices that the visitor should wear at 'Archeoguide' project

Source: (Vlahakis et al., 2002)

Another HMD utilises the MR by being accompanied with a wearable computer, which consists of a power unit, and a small lightweight keyboard. The computer is in a backpack that the user should carry, together with a body motion sensor, AR smart glasses and a headphone. Ergonomically, the system made the user very equipped due to its complexity. Moreover, this system also integrates a sensor to identify the user's location (Sparacino, 2002).

Due to the nature of museum visit and its needs, Damala et al. (2007) validated the nature of wearable devices that the visitor wear from museum professionals. They believed the interaction could benefit from a tiny computer screen for the environment around them. Moreover, the interaction also might cover the inputs and outputs on the system depicted in Figure 2.11 (Damala et al., 2007).

Figure 2.11 Example of a wearable device that Damala et al. (2007) described
Source: (Damala et al., 2007)

The project titled 'ARtSENSE' used MR glasses –depicted in figure 2.12- accompanied by different sensors: biosensors and acoustical sensors. The smart glasses used in this project involved a see-through glass which was capable of projecting visuals over real environments, with the capability to track eye movement and provide the system with the visitor's point of interest (Damala and Stojanovic, 2012).

Figure 2.12 What the visitor can see in ARtSENSE project,
Source: (Xu et al., 2012)

The Microsoft HoloLens was used recently in projects such as the 'HoloMuse', which engages users with archaeological artefacts through gesture-based interactions (Pollalis et al., 2017). HoloLens also has contributed in restoration in Art galleries by adding a virtual extension to the actual antiques (Melnick, 2017). Another holographic project enabled an immersive interaction experience, with a view to exploring the potential of MR in museums (Cortana, 2017). HoloLens has also demonstrated its potential in the gaming industry (Volpe, 2015, Alvarez, 2015) by engaging cultural visitors with gaming activities (Raptis et al., 2017).

After a critical review of all guided methods in museums, considering the guiding concepts, roles and the literature outcomes, these methods did not satisfy all stated guide roles that are required to help visitors to navigate and acquire the required information. Also, the museum guides should not be designed to guide only, but also should be engaging, interactive, and encourage social interactions to ensure the sustainability of their usage. There are some other capabilities that are required to be included, particularly in the AR/VR/MR guides, such as being immersive and presenting visual and audio augmentations. These capabilities can enrich the guiding experience. Therefore, a comparison was conducted between the most recent AR/MR according to the museum guide capabilities and functions (see Appendix B).

2.5 Taxonomy of Functions for MR Guides

This section provides a coherent taxonomy of the functions and concepts that should exist in the museum guidance systems - depicted in Figure 2.13. The taxonomy abstracts the essential and supplementary functions that form the optimum museum guide, which adopts MR technology and devices. This taxonomy is designed to be versatile and can be adapted to many museum contexts and cultural heritage places.

2.5.1 Guidance Provision

Many studies have emphasized the role of guides and the impact of these roles on the museum experience (Hughes, 1991) (Pond, 1993) (Levy et al., 2002) (Zhang and Chow, 2004, Best, 2012). These studies pointed to the actual responsibilities and roles of the tour guides and the impact of considering these roles on the museum experience and the satisfaction of guides. However, these studies specify these roles in terms of the human guides and, they should be taken into consideration when the MR developer intends to introduce a guide to museum visitors. These electronic devices can adopt some of the guide roles (mentioned in section 2.4) depends on the HMD hardware and software capabilities.

Figure 2.13 Museum Guide functionality taxonomy

2.5.2 Immersion

Thanks to the new MR HMDs, the ability to immerse users either in a synthetic world created via computer graphics or mixed realms can be achievable. Moreover, the impact of the sense of immersion during the guiding process was positive in several studies (Pujol et al., 2013) (Blöckner et al., 2009) (Vlahakis et al., 2003).

Museums are designed to a sense of immersion and isolate visitors from the outer world (Harvey et al., 1998). Therefore, designing the museum guides can empower this sense and help change the traditional museum experience.

Immersion theory constitutes the experience of physical interconnectivity between an individual and an encapsulating perceptual stimulus (Bowman and Standiford, 2016). (White et al., 2012). The physiological feeling of being surrounded by a different reality is similar to the perceptual awareness of experiencing virtual reality (Murray and Murray, 2017). Jennett et al. (2008) demonstrated a conceptual overview and defined immersion as "a *gradual, time-based, progressive experience that includes the suppression of all surroundings, together with focused attention and involvement in the sense of being in a virtual world*" (Nacke and Lindley, 2010).

Bitgood (1990) determined four factors for constructing immersing experience: use of the surrounding physical environment, environmental feedback, multisensory stimulation and object realism. Thus, the MR HMDs (as immersive tools) are considered utilities for projecting high-level immersive museum experiences (Brown and Cairns, 2004).

2.5.3 Engagement

Engagement is defined in different manners by different authors (Brodie et al., 2013, Higgins and Scholer, 2009), such as attachment (Dwayne Ball and Tasaki, 1992), or emotional connection (Marci, 2006). Taheri et al. (2014) identified three drivers for engagement in tourism: prior knowledge, multiple motivations and cultural capital. Regarding engagement in museums, it enhances the visitors' consumption experience (Edmonds et al., 2006). Normally, successful engagement is measured in museums by the average time spent in the space. However, the time may be consumed in other facilities in the museum such as the coffee shop (Falk and Storksdieck, 2005). Therefore, engagement for museum visitors is better represented in spending time with the interpretation techniques and creative presentations (Welsh, 2005).

Edmonds et al. (2006) suggested three distinct attributes that are significant for achieving engagement in museums; 1) *attractors,* which are the features that encourage visitors to be attracted in the place; 2) *sustainers*, which are the features that make the visitor keep engaged with the attractor; 3) *relaters,* which are the features that create bonds and relationships between the visitor and the attractor, where it continues and grow for future occasions. By achieving these attributes, the museum guide can engage the museum visitor, then accordingly they can enhance the museum experience.

2.5.4 Contextualisation

The term 'contextualisation' was utilised by Damala et al. (2007) since it refers to situating the museum antique in its original context. It also refers to the visualisation around the object such as images, 3D models, animations and 3D avatars. The goal is to design a contextualised museum guide with multimedia that is capable of enhancing the museum visits (Al Takrouri et al., 2008) (Albertini et al., 2005).

2.5.5 Personalisation

In museum guides, the term 'personalisation' is defined as the line between customisation and adaptability (Damala et al., 2007). Personalisation is also concerning with creating functions based on inputs from visitor preferences and habits (Bowen and Filippini-Fantoni, 2004). Personalisation can enhance the tourist experience (Albertini et al., 2005) (Rutledge et al., 2006).

2.5.6 Communication/Interaction

HCI, in this research, takes the role of communication between the user and the system as a guide tool/method, and it considers this interaction as a method of two-way communication in order to transfer knowledge. Moreover, increasing the level of interaction can enhance the museum experience, more than experiencing technological mediation only (Danks et al., 2007).

Due to using headsets for immersive systems in museums, the expected interaction can be achieved between the human and the surrounding environment, especially with MR HMDs such as HoloLens or Meta 2. These interactions could be achieved by hand interactions (Matt Zeller and Brandon Bray, 2018), eye gazes (Hutchinson et al., 1989, Wang et al., 2018a) and user voices (Sodnik et al., 2006, Cowan and Kapralos, 2008).

One element of human understanding that HCI can support is taking voice input from the user and interpreting it into actions, which is considered a directed method of communication between human and computer (Zeller and Bray, 2018).

2.5.7 Visual Augmentations

Recently, AR has become a significant tool to display visuals in museums (Liarokapis, 2007) (Boland and Johnson, 1996). MR introduces a new information visualisation platform that encourages users to interact with this information and seek further exploration and communication (Meiguins et al., 2006). The recent MR HMDs can provide a wide scale of visual information types and formats (Hammady and Ma, 2019), which can enhance the user's perception of reality (Rauschnabel, 2018).

2.5.8 Audio Augmentations

Museums are a smart environment, whose role is not only to let the visitor explore and gain knowledge, but also generate ideas and learn new concepts (Zancanaro et al., 2003). Moreover, museums can provide a stimulating environment that can support contextual learning for visitors, through inquiry-skill-building and follow-up activities, which can be conducted at home or at schools (Semper and Spasojevic, 2002). Therefore, part of the museum's role is to introduce a multi-dimensional educational institute, which is why museums require additional mediation techniques that can support what is required to fulfil their role.

Storytelling narratives are one of the museum mediations as they are profoundly rooted in human learning due to providing an organised structure for new experience and knowledge (Mandler, 2014). Moreover, the relevant information is better organised in the form of a story and social activities such as plays and performances can effectively be used to share a culture (Falk and Dierking, 2000). Some studies have embraced the storytelling method, which includes a study in a virtual museum (Giaccardi, 2006), and others that consider storytelling a non-formal education manner (Taylor and Neill, 2008) (Zancanaro et al., 2007).

2.5.9 Providing Social Interaction

Providing social interaction functions during the usage of museum guides is considered a vital aspect of the museum experience, as it can enhance and maintain the interest of the exhibits (tom Dieck et al., 2016). Several studies employed social functions in their museum guides (Kopp et al., 2005) (Bederson, 1995a), which can also increase the level of knowledge acquisition within the museum context (Tal et al., 2005).

2.6 Summary

This chapter has discussed the definitions, taxonomy and concepts of AR, along with a new definition of MR. Additionally, it showcased the different hardware, software and devices that are applicable to MR applications. Moreover, it included a literature review of tour guide methods for museums and proposes a new taxonomy of functions for an optimal guidance system, which will be further discussed in chapter 3.

Chapter 3:
Preliminary Studies

3.1 Introduction

This chapter confirms the exploratory study mentioned in chapter 1, by using various data collection methods. This process includes a field study that explores the targeted environment under study and investigates various factors that influence the museum experience. A methodological exploration action was planned to take place due to the lack of essential information that the research could acquire from the literature review. This chapter articulates the preliminary studies that have been conducted at the Egyptian Museum in Cairo. These studies are crucial to the research in order to get a solid understanding of the problem that faces guidance at the targeted museum. Additionally, the researcher seeks to find more contemporary information about the environment of the museum, types of visitors, the ambience of the guidance and some other influencing factors on the museum experience.

3.2 Motivation of the Preliminary study

Firstly, based on the phenomenon of the short length that visitors of the targeted museum stay (see section 1.2), some questions have been raised and need to be answered to get a thorough understanding of the problem. Many factors can influence the length of stay in museums, however, this research mainly focuses on the visual experience in the exhibit. Therefore, the research needs to obtain data about the length of stay in front of exhibits, as this implicates the total length of stay for visitors. The study also investigates specific actions that visitors usually do such as: what does the average of duration visitors spend in front of exhibits; did they read labels; and where do they look/gaze on the exhibits?

These questions are required to understand the nature of visitors and their behaviours. Also, as mentioned in section 2.5.3, measuring the time spent in front of the exhibits can indicate how much visitors are engaged in museums. The answers to these questions can facilitate finding potential solutions or techniques. Moreover, these answers will be considered during the system design process in order to potentially maximise the time spent in museums.

Secondly, there is a need to investigate the guiding methods that routinely run at the museum. As mentioned in section 1.2, the only guiding method introduced by the Egyptian Museum in Cairo is the human guide, and that service was not closely inspected in terms of the way the service is introduced and how it influences the museum experience for guided visitors.

Therefore, the questions raised for the preliminary study include:

- How does the tour guide actually perform during the tour?
- What is the level of satisfaction or engagement for the museum visitors when they use museum guides?
- What is the quality of the service provided?
- Are there any other guiding methods available for visitors?
- What is the potential for adopting new technologies to take over (or complement) the human guides in the museum?

These questions are required to assess the current guide methods that run in the targeted museum, understand their fundamental role, and investigate the best features of it. These investigations can help the research to acquire a more thorough practical understanding of the guide roles in order to be useful as inputs in the process of creating an alternative guide. This guide can take the privileges of the current guide and employ more features covered in the literature review.

Additionally, some other problems exist in the museum, such as the exhibition setup, guiding manners, and the ways of presenting information to visitors. These problems might affect the daily visitors' museum experience and causes a drop in the numbers of visitors annually. Realistically, not all of the aforementioned problems will be tackled, so this research seeks to solve problems that are relevant to the visual experience.

3.3 The Preliminary Study

This stage of the research is an exploratory study, which intends to answer the aforementioned raised questions via a field study. It is considered most critical due to its relevance in gaining insights about the museum atmosphere and the salient obstacles, as discussed earlier.

The exploratory study also adapted it aims to obtain a full understanding of the salient problems, which may be unknown to the researcher. Therefore, it is considered qualitative research, since it tends to use the interview technique as part of the data collection method. The rationale behind using an exploratory study instead of a descriptive study is that the latter is considered a quantitative study that seeks a precise description of an apparent problem. Moreover, the descriptive study - as a research design - seeks to assure the preciseness and the accuracy of signposted factors by using surveying as a data collection technique.

The most recommended qualitative data collection techniques for exploratory research are semi-structured interviews or in-depth individual interviews and participant observation. Choosing the most appropriate data collection technique depends on how efficient this tool is in answering the raised questions. As shown in table 3.1 and table 3.2, the questions required are summarised, the research method is employed to answer these questions, and other studies have adopted it.

Table 3.1: Observation methods and studies related

Questions	Method	Previous studies
What is the average length of stay in front of exhibits? (time/item)	Observation	(Yoshimura et al., 2016)
What are the certain actions that museum visitors usually do in exhibits?		(Bollo and Dal Pozzolo, 2005) (Lanir et al., 2017)
Do museum visitors usually read labels?		(Smith et al., 2017)
Where do the visitors' usual gaze usually when they look on the exhibits?		(Vom Lehn, 2006) (Vom Lehn et al., 2001)

Table 3.2: Interviews methods and studies related

Questions	Method	Previous studies
How does the tour guide actually perform during the tour?	Interviews (unstructured /In-depth)	(Karreman et al., 2012) (Shearing and Kempa, 2004) (Zhang and Chow, 2004)
What is the level of satisfaction or engagement that the museum visitors have when they use museum guides?		(Zhang and Chow, 2004)
What is the quality of the service provided?		(Jago and Deery, 2002)
What is the potential for adopting new technologies to take over the role of guide in this museum?		(Wakkary et al., 2009)

3.4 Participant Observation

Generally, observation (as a data collection technique) aims to reveal a description of a subject's behaviour. It gives the researcher much more control over the environment of the action. Participant observation is well known in the field of sociology and anthropology, due to observing human behaviours (Jorgensen, 2015). Participant observation is commonly used when the research applies the ethnography approach (AKTINSON and Hammersley, 1998). In that approach, the researcher is entirely involved with the scene of action, and he/she is involved with two roles: overserving and participating. Therefore, the observer may talk, live and immersively participate with audience life. However, this is not the proper type of observation that the researcher is willing to achieve.

The observation method aims to record visitors' behaviours in the actual environment regarding the antiques exhibited. These behaviours include their movements, time spent next to/ in front of the antique, and how they react, as well as, some indirect behaviours such as their feelings, and level of interest, level of engagement with the objects. The other aim of using observation is to conduct a critical comparison between the human behaviours in the current state of museum guidance and these same behaviours after applying the research solution. This comparison should visually demonstrate the differences in behaviours and how visitors react in both situations.

The observation method has been frequently in museums to understand visitors' behaviours (Lanir et al., 2017, Thrun et al., 1999a, Bollo and Dal Pozzolo, 2005). Many museum studies relied on specific measurements to assess how people were attracted to exhibits such as *'Attracted Power'* and *'Holding Power'* (Lanir et al., 2017, Bollo and Dal Pozzolo, 2005, Hooper-Greenhill, 2006, Serrell, 1997).

'Attracted Power' is measured by the number of visitors who have stopped in front of the exhibited item. This measurement informs the preliminary idea of the power of attraction for the exhibit of the study (Bitgood, 2017). However, '*Holding Power'* is measured by calculating the total time spent in front of an exhibit, and is used to measure the visitor's interest. This measurement informs the preliminary idea of the power of an exhibit to hold the interest of a visitor (Bitgood, 2017).

Indeed, this study does not need to investigate the extent of the power of the exhibit as an attractor, since it is more concerned with the significance of the museum's exhibits. This study focuses on measuring how the visitor is attracted to and engaged with the exhibit, and this is what this research intends to investigate and develop.

3.4.1 Classification of Observation

The position of participant observation among the observation methods in psychology is depicted in Figure 3.1, as created by Shaughnessy et al. (2000).

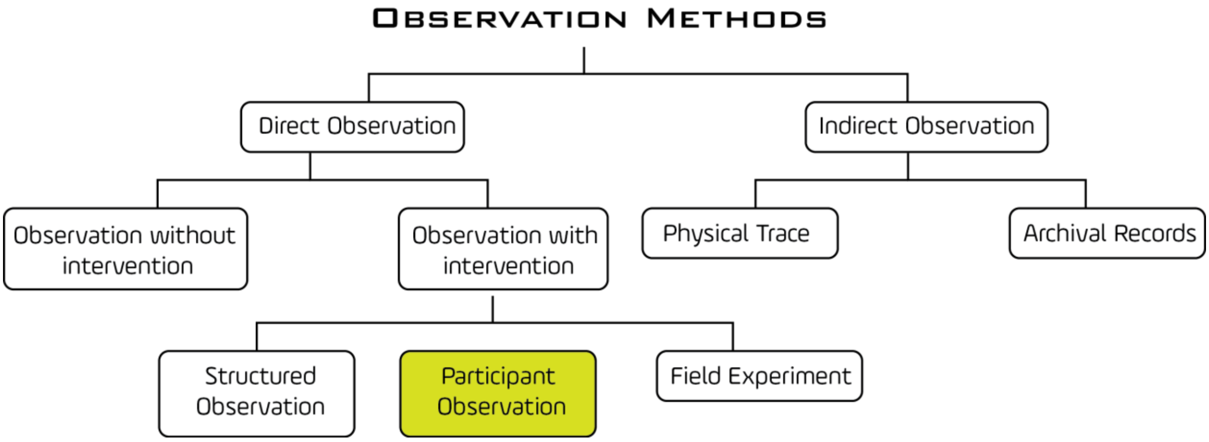

Figure 3.1 Observation methods by Shaughnessy et al. (2000).

Figure 3.1 specifies the location of participant observation in the observation methods diagram. Regarding our study, the researcher should remain an observer of human behaviours in the scene of action and avoid any intervention of the visitors' actions. Confusion might occur due to not considering the activity as 'Observation without intervention', often known as naturalistic observation. Naturalistic observation usually takes place in the lab in the natural sciences, where the researcher is not aware of the measured aspects he/she is going to observe (Angrosino, 2016). However, in the present study, the researcher will be present in the scene of action, therefore, it underlies observation with intervention.

In participant observation, the observer has two roles: observing people's behaviours and participating actively in the same environment. However, there are different levels of participating with people, based on being a disguised observer or undisguised observer. In undisguised participant observation, people can acknowledge the presence of the observer and the purpose of the data collection. On the other hand, if the observer is disguised, people cannot know that they are being observed so that they will behave spontaneously and in a natural manner (Shaughnessy et al., 2000). The current study takes the disguised participant observation approach. Saunders (2011) developed a topology of participant observation roles, which is depicted in Figure 3.4.

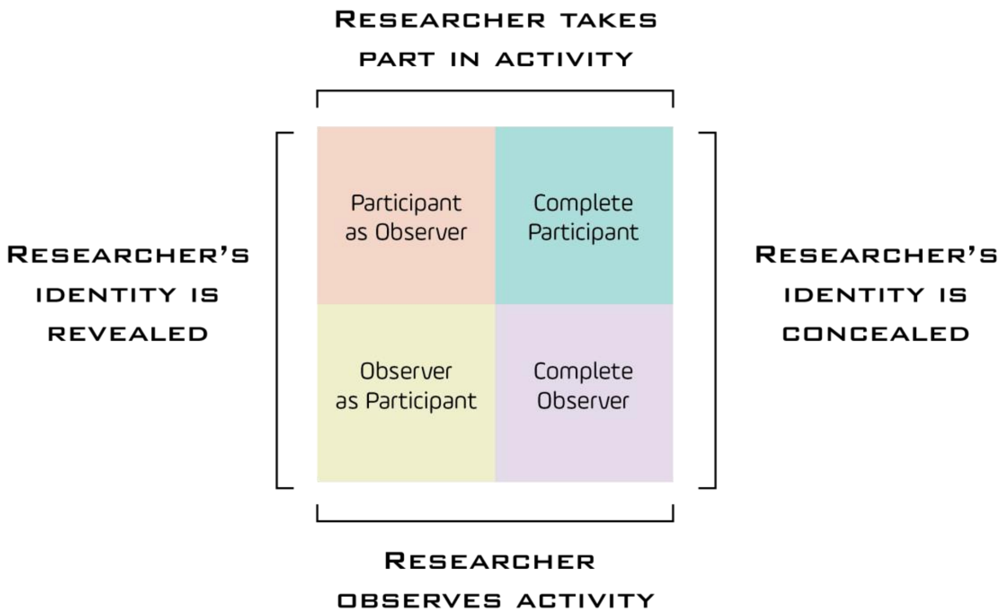

Figure 3.2 Topology if participant observation by Saunders (2011)

The activity of observation in the current state took the stance of being a 'Complete Observer' , as per the Saunders (2011) framework. The rationale is that the researcher identity needs to be concealed, and the audience should not be aware of expect the reason for recording their behaviour.

The researcher intended to record videos of visitors at the Egyptian museum rooms. Thus, ethical approval and the required permissions were considered in order to conduct the recordings at the museum, as it is continuously observed by CCTV. Considering the museum is a public place, observational research is acceptable where those observed would expect to be observed by strangers. Also, to avoid the Hawthorne effect (Adair, 1984), visitors were not aware of being filmed during their tours.

The recording procedures included two different types of visitors: the visitors who are unguided, using any types of available guide methods, and visitors who are guided by a method of museum guides.

3.4.1.1 Sampling the Unguided Visitors

A- The activity description

Observation during this phase involves watching what people do on their tours, where they gaze, their movements in the room, time spent in front of exhibited artefacts, how they stand, and how peers interact with each other. This observation was induced randomly, so that the observer did not focus on a specific group or rely on a controlled group. Therefore, it's an observation of natural touring which routinely takes place in that room. This type of observation was done using videography, by setting up a static camera to capture the unguided visitors.

B- Rationale behind observing unguided visitors

The main aim was to observe the flow of visitors' activities, which are done routinely in the museum. This method also can help confirm what was claimed regarding museum engagement. It helps the researcher generate new ideas that are relevant to the action scene.

In addition, it can help the researcher conduct an explicit comparison between both methods of guidance, based on the recorded observation, both before applying the solution and after applying it. In this case, research can identify changes in visitors' behaviour and how it can be altered by the replacement substitute.

C- Criteria of observation

Realistically, the researcher cannot record all of the occurrences. Therefore, it should consider specific criteria for recording and sampling the data. The researcher - as the main observer of the scene of action - drew circles of movements and noted when visitors switch their attention between an exhibited artefact to another. Also, the time that elapsed for each artefact was considered in addition to how the visitor's gaze moves around the artefact.

3.4.1.2 Sampling the Guided Visitors

A- The activity description

Observation in this stage included the tour guide and his/her followers, or any visitor who adopted guide methods such as books or electronic guides. This stage was conducted by recording what people do in their tour such as how visitors follow the tour guide's explanations acoustically and visually, where they gaze when the tour guide points to a specific spot, and time spent in front of the exhibited artefact. This observation was also induced randomly so that the researcher did not focus on a controlled group. It is an observation of natural touring, which routinely takes place in that room.

B- Rationale of observing guided visitors

This method aids the researcher in establishing a general assessment of the workaday tour guiding. It also provides a second tool of investigation on the current guided methods that occur in the targeted museum.

C- Criteria of observation

In this case, the researcher had to focus only on tour guides and their groups, or those who adopted other guided methods. Also, filming several groups at different times in the day was considered in order to achieve the generalisation factor.

3.4.2 Sampling Behaviour

The approach of the *random time sampling technique* was considered in sampling the unguided visitors in order to apply generalizability to the investigation activity. However, sampling the guided visitors involved the *situation sampling technique* in order to conduct observations of specific circumstances and conditions. Furthermore, situation sampling can increase the external validity of the findings (Shaughnessy et al., 2000).

3.4.3 Participant Observations Analysis

Five video clips were recorded in the room of King Tutankhamun, which is located on the second level of the Egyptian museum. Table 3.3 shows the duration of this footage, including the availability of guided and unguided participants.

The analysis strategy involved the deployment of some tools to control the existing variables, such as the number of cases, the exhibited antiques, the nature of the behaviours, gaze points, time elapsed, and any unexpected actions from visitors during observation.

Table 3.3: Details about the recorded observations in the Egyptian museum's room

	Clip 01	Clip 02	Clip 03	Clip 04	Clip 05
Duration	10:07	00:48	00:10	12:07	01:56
Includes guided visitors	Yes	Yes	No	Yes	Yes
Includes unguided visitors	Yes	Yes	Yes	Yes	Yes

The exhibited items involved in the observation are shown in Figure 3.3. The camera was fixed to different locations at different times. These items are a set of the most significant collection in the museum since they belonged to King Tutankhamun who was a famous Egyptian Pharaoh of the 18th dynasty (De Luca et al., 2001). Due to their popularity, museum guides usually spend more time in this hall, which features popular items such as the throne and a collection of mannequins. According to several interviews with experts and curators who work in this hall, these particular antiques – depicted in Figure 3.3 - require (1-2) minutes as sufficient time to stay next to each of them for gazing and reading labels. This value represents the *'utilisation time necessary'*, which is required for the later observation analysis.

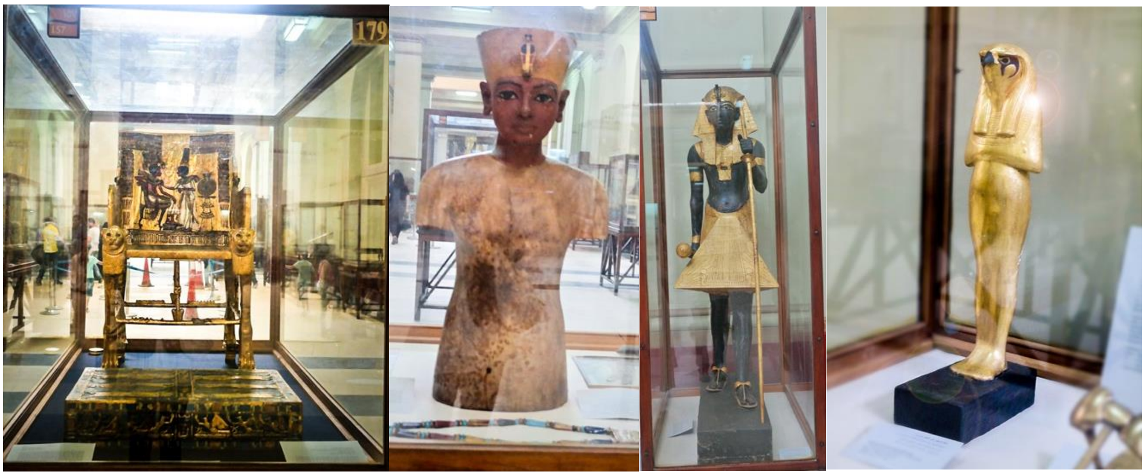

Figure 3.3 The Exhibited items that visitors observed in the Egyptian museum, from left to right: (A. The Golden Throne, B. The Mannequin, C. Statue of Tutankhamun, D. Statuette of the god Harwer)

The observation analysis deployed video editing tools to detect the cases and to set a time counter for them, as depicted in Figure 3.4. Moreover, the editing tools assisted the observer in getting a closer look at the participants' gaze points during their visit. The following table presents twenty cases of participants. Some of them were in a group, and others came alone. Five cases used a guide during their visit (highlighted in the table), whereas some of them followed a human guide, and others used a guide book. The study considered the sampling of the guided visitors in the room being observed. The next table (3.4) depicts the observation measurements, which include:

1. Number of cases: either an individual visitor or a group.
2. Description: a brief description of the case observed.
3. Object number: museum objects either A, B, C or D depicted in Figure 3.3.
4. Nature of behaviour: what visitors actually do during their tour.
5. Gaze points: focuses on where visitors look on the exhibited item.
6. Time elapsed: the total time visitors spent in front of the items.
7. Other activities: unexpected behaviours that can define the different patterns of the museum visitors.

Table 3.4: The observation qualitative results

Cases	Description	Obj. Num	Nature of Behaviour	Gaze Points	Time Elapsed /Sec	Other activities
Case 1	A lady accompanied with a gentleman and three kids	D	Both of them look into the glass box	The statue and the label	06	The gentleman and the lady talked to each other about what they saw
Case 2	A lady accompanied with a gentleman	B	The lady kept looking at the statue while the gentleman stopped looking	The statue from 3 sides and the label	45	The lady span around the glass box giving more attention to the statue, then she started to read the information on the label
Case 3	A lady accompanied with a gentleman	A	The lady had a quick look	No gaze points	01	The lady stood next to the statue and the gentleman took some photos for her with the statue
Case 4	An old man accompanied by three ladies	A	The gentleman went closer to the statue and then moved to the label to read it carefully. Once the old man saw the item, he started to speak with the ladies about what he saw	The statue and the label	07	When the gentleman starts to move his gaze to the label, he wears his spectacle to read carefully.
Case 5	A lady who came alone	A	The lady goes directly to the label to read it	The item and the label	20	Most of the time spent was reading the label with a quick look to the statue

Cases	Description	Obj. Num	Nature of Behaviour	Gaze Points	Time Elapsed /Sec	Other activities
Case 6	A gentleman accompanied by a lady	A	The gentleman span around the statue from the four sides as he showed more interest in the piece.	The right side of the throne then the 4 sides of the item	29	The gentleman started to read the label loudly to the lady
Case 7	A gentleman accompanied by a lady	D	The gentleman showed more interest in the piece. A third of the whole time is spent in reading the label	The statue's face and the label	50	The gentleman read the label loudly to the lady and pointed with his fingers to the head of the statue, then he took a photo of the lady with the statue
Case 8	A lady who came alone	A	A quick look to the item	No specific gaze point	01	She took a selfie with the golden throne
Case 9	The tour guide with a gentleman and a lady	D	The tour guide pointed and explained to both of them and they kept seeing the statue	The statue's face and the label	18	The gentleman and the lady spoke with the tour guide
Case 10	The tour guide with a gentleman and a lady then another lady joined the group	A	The tour guide pointed and explained to both of them and all of them span around the 4 sides of the item	4 sides of the item	111	A lady (looked local and trying to understand the language) joined the group and stood beside them to hear the tour guide for 105 second
Case 11	A single young man holding a book	C	A general look and a closer look slowly from the top of the statue to its legs	2 sides of the statue	22	The young man looked at the statue with concern exploring details. He looked as if he is interested in the details of the statue

Cases	Description	Obj. Num	Nature of Behaviour	Gaze Points	Time Elapsed /Sec	Other activities
Case 12	Two ladies, three girls and a boy	B	One lady started to speak about the item, and the kids kept listening	4 sides of the statue	105	The kids took pictures of the statue from the 4 sides
Case 13	A lady then another lady came closer to her	D	The first lady came closer to the statue and explored, then another lady came	7 gazes (face, body, foot, label, other antiques)	120	The first lady was so interested, and she looked like she knew what she was looking at. Then, they invited the other lady to see then she started to explain to her what she saw
Case 14	A gentleman by a lady	D	The gentleman saw the statue then let the lady see what he saw	4 points (Statue face, bottom, label, other antiques)	22	The gentleman looked interested, then he pointed with his hands to the lady, and he explained what he knew without reading the label
Case 15	A lady who walks alone	D	The lady kept looking and reading the label	3 points (top, bottom, label)	34	Most of the time spent was in reading the item's label
Case 16	Two gentlemen and a lady	A	Two gentlemen examine the throne from all sides and span around it	5 points (right side, bottom, back, front, chair legs, labels)	30	They kept looking to the stories engraved on the chair and they discussed what they saw
Case 17	A tour guide with a group of two gentlemen	A	The tour guide pointed to specific points on the item	3 Points (front, right side bottom)	20	Nothing special. However, they did not read the label; they just listened to the guide.

Cases	Description	Obj. Num	Nature of Behaviour	Gaze Points	Time Elapsed /Sec	Other activities
Case 18	A Lady with a book	A	The lady kept reading then spent even duration in each side of the item	5 points (front, back, right side, left side, label)	91	She took pictures of it, then she moved around the throne and explored every side of it
19	A lady with three kids (a girl and two boys)	A	The lady read the label loudly to the kids then they looked together at the throne	2 points (left side and the label)	20	They took a 'selfie' together with the item
20	Two young men walking together	A	They span around the item from the 4 sides and read the label	All sides of the item	60	Spinning around the item twice looking closer to the small details and pointing to these details.

Figure 3.4 Video software deployed to calculate the time elapsed by visitors in front of exhibited items

3.4.4 Findings of the analysis

The outcomes of the analysis involved two parts: quantitative and qualitative. The quantitative part focuses on the length of stay and the qualitative part focuses on an interpretation of the visitors' behaviour.

<u>Quantitative results: Holding power and average timing</u>

The average of the time spent is =

(total spent time by sampled visitors) 812 ÷ (number of sampled visitors) 20 = 40 sec.

Utilisation time necessary = between 1 to 2 minutes = 90 second (average).

The utilisation time necessary is defined by Bollo and Dal Pozzolo (2005), who write that *"The calculation of the "necessary" time is established by the researchers, who measure the time that is essential for the entire communication about a particular object to be taken in*".

Holding Power index = $\frac{Avarage\ stopping\ time}{Utilisation\ time\ necessary}$ = 40 ÷ 90 = 0.4.

As Bollo and Dal Pozzolo (2005) stated: *"The closer it is to 1, the greater ability of the element to hold the visitors' attention will be"*.

Qualitative results: forming patterns

The analysis used '*descriptive analysis'* which works by transforming and interpreting the visual and audible information to written text (Flick, 2013). The raw data from the recorded videos, therefore, needs to be interpreted into meaningful information, i.e. classification of behaviour patterns.

Pattern 1:

Regarding the social aspects, surprisingly, 4 out of 5 cases from visitors who spent more than 60 seconds were in groups and only in one case the visitor was walking alone. Also, 3 out of 4 cases from visitors who spent more than 30 seconds to one minute were in groups and only in one case the visitor was walking alone. These results indicate that being a part of a group motivates the visitor to have more interest and consequently maximises the time spent in front/next to the exhibited item.

Pattern 2:

Regarding the guide aspect, 3 out of 5 cases from visitors who spent more than 60 seconds were either following a tour guide or using a guide book. Therefore, the guiding methods affect the time spent in front/next to the exhibited item.

Pattern 3:

Reading the text on labels took a considerable amount of time for the observed participants. In cases, 2, 5, 7, 15 and 19 visitors took much time in reading the labels more than gazing at the exhibited item itself. However, in cases 6, 15 and 19, one of the visitors' groups read loudly the content of the labels beside the items.

Considering museums as an entertainment environment and an interesting atmosphere to discover and retain knowledge, the aforementioned cases were divided among the gazing points unfairly. Visitors spent more time to read instead of exploring the valuable antique. However, some visitors tended to take the role of an audio guide narrator to compensate his/her absence. This problem presents the researcher with the possibility to create a more efficient substitute, instead of reading a long document of text.

Pattern 4:

The tendency to take pictures and selfies were evident in many cases (3, 7, 8, 12, 18 and 19) that were observed in the targeted room. Taking pictures with the exhibited item or recording a moment with the item simples a specific interest in this piece over any other exhibited piece in the room. This pattern provides the researcher with a rationale to implement such a feature in the MR guide.

3.4.5 Observation Findings Conclusion

This section articulates the final findings of the observational studies, after the subjective qualitative analysis that the researcher conducted – depicted in Figure 3.5. These findings redirect the researcher to generate ideas that can exploit the factors that aided the extension of time elapsed in front/next to the exhibited antique. Moreover, these findings depicted problems, which also encouraged the researcher to consider a substitute solution in the next stages. Furthermore, the findings also revealed unexpected behaviours, which are factors that can be considered in the proposed system. These factors are taken from the place of action with the same context, in order to propose a system that can fit the context and the environment that it is designed for.

Moreover, the time visitors spent in front of the antiques based on the holding power measurement was 0.4, which is below half the recommended time spent according to the significance of these items. These results indicate a significant engagement problem in the museum room of study.

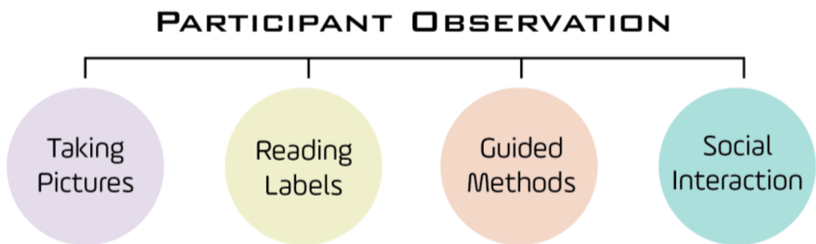

Figure 3.5 Findings of participant observation study

3.5 Semi-Structured Interviews

'Semi-Structured Interviews' refer to the context, wherein the interviewer has a series of questions that have the flexibility to be posed in a different sequence if necessary. However, the manner of questioning and responding might differ from the list of questions based on the situation. Moreover, in this manner, the interviewer has some leeway to ask further questions as a response to unexpected answers or responses due to the potential ambiguity of the answers (Bryman and Bell, 2011). It is predicted that the semi-structured interview will omit some questions in particular interviews, although this will depend on the individual respondent's case. It is common for the interviewer to offer some comments to encourage the interviewee to have an open discussion regarding the topic of the question (Saunders, 2011).

Due to the nature of this study being an exploratory study, this research exploits this approach of interviews in order to acquire some explanation from the actual visitors and some of the museum curators.

An 'unstructured interview', sometimes known as an 'in-depth interview' is usually informal and used frequently for exploration. Moreover, it does not have a prepared list of questions. The researcher in this situation needs to have a good understanding of the aspects of the topics discussed with the interviewee. Furthermore, the interviewer has the opportunity to talk about behaviours, beliefs or particular events that are related to the topic. Therefore, this type of social interaction is known as non-directive (Saunders, 2011).

The previous manner of interviewing is suitable for this phase, however, it depends on the case itself. In other words, if the interviewee has a unique and considerable experience in the field of guidance or the touristic experience, the unstructured interviews will be more significantly beneficial to the exploration study.

3.5.1 Interview Contexts

Many forms of interviews can be employed according to the manner of interviewing and the nature of the interaction between the interviewer and the respondents. A topology introduced by Saunders (2011) is depicted in Figure 3.6 in order to show the form of the presentation that will be utilised in the current studies. The nature of this study is to explore the physical environment and add greater credibility to the research and the researcher, as the interviewer approaches the face-to-face interviews. Face-to-face interviews reflect a greater level of realism to the research, as the interviewee will respond effectively in the scene of action more than being out of it.

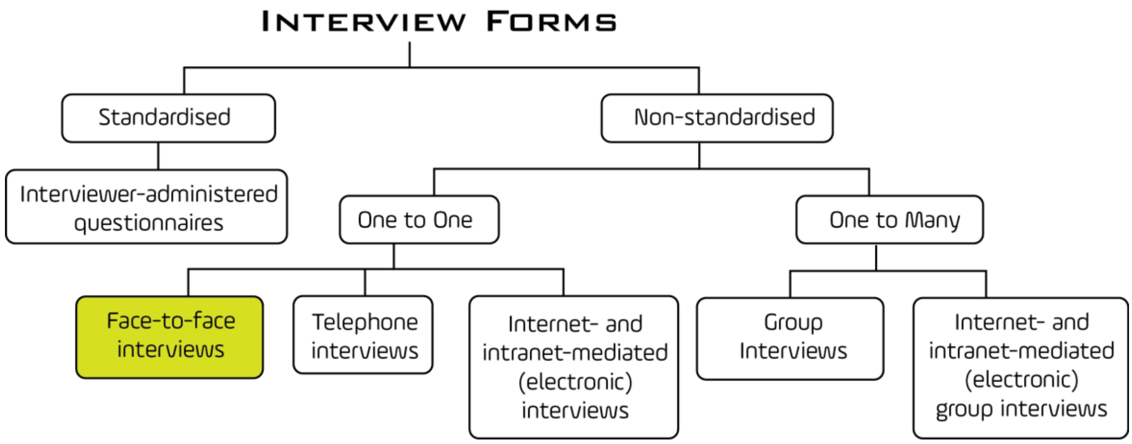

Figure 3.6 Interview forms created by Saunders (2011)

The interview questions were developed from the raised questions that were illustrated earlier in table 3.2, which were integrated with open questions in order to captivate the respondents and reveal information about unexplored areas. Additionally, the questions should be dedicated to two different kinds of visitors: guided and unguided visitors.

Based on the discussion of the interview types in the previous section, the interview type in this study will be semi-structured interviews. The rationale is that it will involve more open questions to cover unexpected aspects in the study and will fit the nature of exploration at this stage.

3.5.2 Ethical and Authorization Considerations

The researcher is keen to provide the necessary formal ethical documents to each respondent in order to guarantee question filtering from personal violations during the interviews. Interviewing verified permissions are also showcased to the participants. However, permission about interviews was included only the museum garden so all interviews should not be conducted at the museum building.

3.5.3 Sampling

Due to the instructions that international visitors receive and follow from the tourism authorities in Egypt, who advise them not to become involved with anonymous people, it was not easy for the researcher to introduce himself to the prospective respondents. Indeed, these circumstances significantly affected the sample size of the interviewees. However, the researcher still managed to reach a satisfactory number of interviewees by overcoming these difficulties.

The researcher conducted ten interviews with regular visitors to the targeted museum, eight of which were local visitors, and the ninth was an international visitor. This sample is acceptable according to Creswell and Poth (2007), who considered five to twenty-five participants to be satisfactory. Nine of the interviews were conducted as semi-structured interviews, so the questions were less organised, open for discussion and encouraged respondents to eveal what the interviewee had in his/her mind regarding the topic of interest. Two of them, fortunately, used tour guide services and the remainder did not. Moreover, the researcher was fortunate when he interviewed a particularly interesting person for the research. This person spent his entire professional life (more than forty years) in the field of museology, in particular in the Egyptian museum in Cairo, starting by working as a tour guide and eventually becoming a former director of the Egyptian museum itself. Indeed, interviewing this person was most valuable to the research, due to the long and comprehensive experience he has in this museum. Additionally, he has lengthy experience of tour guiding, as he revealed various untold facts about the service of guidance in the museum. Therefore, interviewing this person drastically changed the interview type from being semi-structured to an unstructured/in-depth interview. The chance for conducting probing questions is therefore high due to his knowledge about the nature of the museum environment and the problems of guidance that the museum suffers from.

3.5.4 Interview Analysis Process

The interview data analysis is comprised of several actions, such as dealing with the mass of paper and electronic files, exploring, analysing, transforming and synthesising data in order to address the required findings (Saunders, 2011). Data analysis in qualitative research also involves a set of processes, such as creating nodes, summarising, categorising data then grouping it according to themes in order to make sense of the data collected.

There are two approaches to the data collection analysis: deductive and inductive approach. The deductive approach relies on an existing theory in order to form the research questions and consequently develop the interview questions. If a deductive approach is adopted, it is expected that the main variables, components and themes are clear to the research in order to build an analytical framework. Therefore, the former approach fits with the nature of the explanatory study, which is not the current nature of this study. The inductive approach relies on collecting data, then exploring them to identify the themes and issues that the researcher is required to follow up on and consider (Saunders, 2011). The inductive approach is embraced because the theory emerged only based on the process of data collection and analysis. Also, the inductive approach embodies the less structured interviews, and relies on contextual interpretation more than rules, as depicted in Figure 3.7, which Saunders (2011) developed.

Figure 3.7 inductive and deductive approach by Saunders (2011)

3.5.5 Thematic Analysis

The purpose of using a thematic data analysis is to provide core skills to the researcher in order to conduct many forms of qualitative analysis (Vaismoradi et al., 2013). Thematic analysis is defined as "*a method for identifying, analysing and reporting patterns (themes) within data*" (Braun and Clarke, 2006). The process of thematic data analysis considers the latent and manifest content and also forms patterns in the themes categorised from the data.

As previously mentioned, the approach considered for this study is inductive. So, the inductive thematic approach in this study means that the themes that have been identified are intensely relevant to the data themselves. Also, the themes that developed during these procedures may be less linked to the interview questions prepared for the data collection method. They might also not be driven by the research's theoretical interest.

The thematic analysis is comprised of six stages and was demonstrated by Braun and Clarke (2006) to be an outline guide for the whole process, as presented in Figure 3.8. It appears to be a linear process which means the following stage comes after completing the previous stage. However, this process is recursive, which means it might involve moving forward and backwards if needed (Braun and Clarke, 2006).

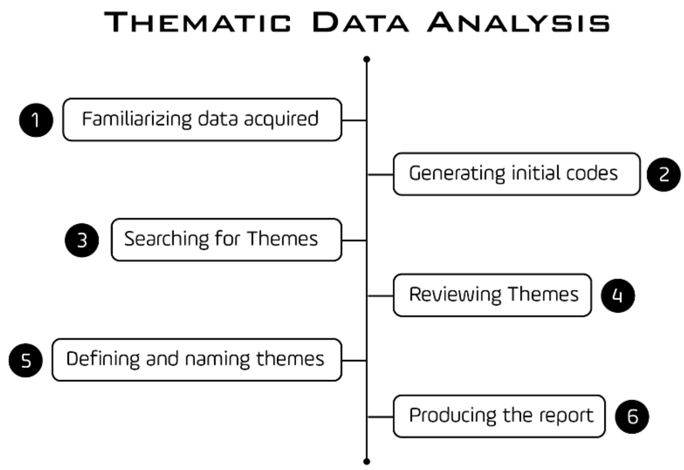

Figure 3.8 Thematic analysis process steps by Braun and Clarke (2006)

Phase 1: Familiarizing data acquired

The first phase of the analysis is to prepare the recorded data for the next step. The interviews were collected by audio recordings that were incorporated with some paper notes and handwritten comments. Thus, this step is concerned with gathering all of these materials in order to process them by 'transcribing data' to electronic text in order to validate it as an input for data analysing tools. In fact, the transcribing process embraces data interpretation and provides the transcriber with a thorough understanding of the data. Also, due to the use of two languages by the interviewees (Arabic and English), transcribing was done first, then the Arabic transcripts were translated into English.

Transcribing the audio files was conducted manually by the researcher himself to avoid misunderstanding the word meanings. Moreover, anonymity privilege was given to those who requested it. Furthermore, each interview is achieved in a separated file and saved and secured for confidentiality reasons.

Phase 2: Generating initial codes

This phase is concerned with creating an initial list of ideas that were extracted from the data and that hold the interest of the research. In other words, it involves converting the raw data to initial codes (Saldaña, 2015). The coding process was conducted using qualitative data analysis software 'Nvivo' in order to work systematically with the entire data set. Moreover, giving equal attention to all nodes that might have an interest to the analyst. It also helps the analyst to form similar cases and patterns (themes) among the data set.

Phase 3: Searching for Themes

After collating codes during the previous phase, the researcher must make sense by gathering them into meaningful groups known as themes. These phases focus on collating all relevant codes into codes that express the same aspect. Visual representation was used in this phase by creating illustrated mind maps integrated with colour coding to differentiate between the themes and the sub-themes.

Phase 4: Reviewing Themes

The themes at this stage become more organised, more combined, refined and are either separated or discarded. Therefore, it became important to consider whether the candidate theme is logical or not. Reviewing the themes on this level also considers the coherence of the created patterns. Moreover, this is achieved by detaching the irrelevant nodes from themes and reconnecting it to the most relevant ones. By the end of this phase, the thematic mind map is satisfactory and presents all significant aspects that are explored during the data collection method.

Phase 5: Defining and naming Themes

At this stage, the thematic mind map arrived at the maturity phase and includes defining and refining the names of the themes according to the explored aspect. So, the themes are given names, which represent the significant aspect as shown in Figure 3.9. the developed themes of this analysis named as:

- Tour guide problems.
- Guide for local visitors
- Prefer tour guide or not?
- Audio guide.
- Potential for headset guides

Phase 6: Producing the report

This phase begins once the map is clear and the analyst can see all aspects together in one map. Therefore, the interpretation will be more highly concentrated among all aspects without neglecting significant information. The rationale behind explaining all the phases that were used during analysis is to prove the validity and merit of the analysis process and give creditability to the results.

3.5.6 Findings of the analysis

Based on the themes depicted in Figure 3.9, the following findings discuss each theme based on the responses of the interviewees. It also includes arguments in terms of how these aspects are relevant to the research and how it could be a potential threat to the research. Also, the discussion shows a clear indication of which methods of guidance are desirable and which are not.

Theme 1: Tour Guide Problems

The current guiding method in the Egyptian Museum is human guides. However, it is a human performance, which might be preferable due to the privilege of human interaction which does not exist in any other guiding method, this method has some negative aspects that might affect the quality of the guidance.

A. The pace of human guides may be too quick for some visitors due to the limited time of the planned tour, which could make the audiences unable to follow the guide's commentaries.

B. Headphones are not provided prior to touring. However, the environment of the museum is too crowded and noisy. The reason for that is the lengthy procedures of renting the headphones. The respondents stated that the tour guide usually does not have much time to go through the procedures of renting, so they ordinarily neglect it. Thus, distraction became a factor in the formula of this manner, which consequently diverts the visitors' focus out of the content of the commentaries.

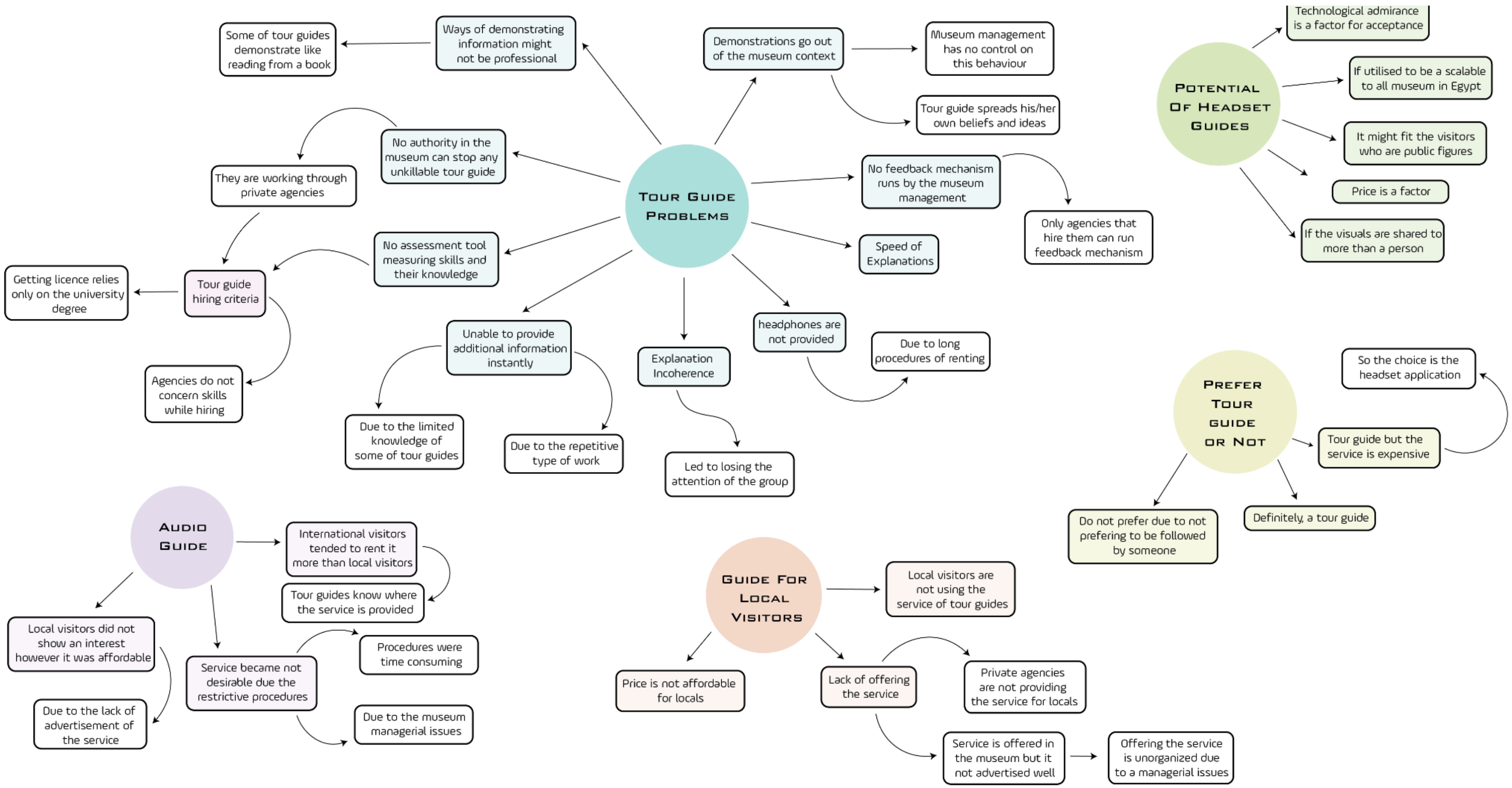

Figure 3.9 Thematic analysis using mind maps as a visualisation tool

C. An incoherence in the explanations might have occurred due to low skill tour guides. This problem might lead to losing the group's attention. This factor strongly relies on personal skills, and it differs from one person to another. Indeed, this drawback requires training, experience and further preparations. However, there is no training programme for tour guides, which is considered a significant problem for the quality of the guide service.

D. There is a lack of provision of additional information instantly if visitors ask a question, as one of the respondents said, *"I consider that happens because the tour guide has a repetitive kind of work, so he was always saying what he used to say".* Apparently, limited knowledge could be a significant reason behind this aspect.

E. No assessment is available to measure a guide's skills and knowledge. As one of the respondents stated, "*there is no control on the tour guides and their skill levels or even assessing them".* The assessment, in this case, implies a judging tool, which could be granted by working as a guide in the museum. However, unfortunately, the tour guide gets his/her job from private agencies, which have no connection with the administration of the museum. This point will be explained later in the next aspect.

F. The museum management of the tourism ministry has no authority to prevent unskilful guides from providing a low-quality service because they are contracted directly by private agencies. However, there are no criteria for hiring tour guides by these agencies, except for the acquisition of a tour guiding licence. This licence is granted to graduates of the school of archaeology. Moreover, the respondent stated that "this licence does not require skills or tests to pass in order to obtain it". So, a fresh graduate might have the same chance as an experienced one.

G. Some methods of demonstrating information might not be professional. As the previous director of the museum stated, *"for example, some tour guides say what is exactly in books. I always consider the last example of tour guides as a failure. Museum visitors can read books about Egyptian archaeology and in* *this case the tourist will no longer need the tour guide's service".* Therefore, if a person has this negative aspect, there is no tool to figure it out due to a lack of feedback mechanisms.

H. Demonstrations go out of the museum context. Some human guides tend to speak about some topics that are irrelevant to the topic of the context. As the former director of the museum mentioned, *"the major problem is when the tour guide leaves the context of archaeology narratives and starts to go out of the text and express his own ideas or beliefs".* This problem cannot be controlled by any authority, either from the museum or the agency they are working for.

I. The mechanism is not administered by the museum, but by the agency for whom the guide works. These agencies gather feedback through verbal or written questionnaires. However, their feedback does not actually represent the museum experience; it is a more holistic experience that includes other aspects not related to the museum visit travel assistance. In other words, it is not particularly made for museum guidance. Also, their feedback regarding museum guides does not have a significant impact on museum management.

Theme 2: Tour Guide for local visitors

Most of the respondents that the researcher came across expressed no interest in using the service of local guides. The analysis reveals some reasons, which are detailed below.

A. The price was not affordable for locals, as the former director stated, *"the price of the service for the local visitor is considerably high. I believe 95% of the local visitors could not afford to rent this service, especially, if they are a family. Besides, the tickets are a little bit expensive".* Moreover, another local visitor said, *"I prefer the tour guide, but the problem is the service is so expensive".*

B. There was a lack of offering of local guide services for local visitors. The reasons for this are emphasised in three points. Firstly, private agencies do not offer this service for local visitors, they only offer tour guiding for international visitors. Secondly, the museum management provides it, but there is a lack of advertisement for this service. Thirdly, the service in the museum is not well organised due to managerial issues. The former director of the museum said that *"this tour guide will be available in the museum if the service is requested. However, the system that made them organise their turn was not organised"*. Although the service was available in the museum, *"this service stopped after the 25th Jan 2011 revolution"* the former director said.

Theme 3: Prefer Tour Guide or not

The respondents were asked during the interview about what they prefer out of choosing a human guide or other guided systems. One respondent went directly to the choice of the human tour guide. Interestingly, some visitors considered that the price of the service is all that can control the choice, as one respondent said *"I prefer the tour guide, but the problem is the service is so expensive. Therefore, I would go to the headset application"*. Another respondent did not show an interest in choosing the human guide due to the restricted instructions that some people do not prefer.

Theme 4: Audio Guide

The analysis released significant information about the digital guide that was used by the museum visitors. As the former director of the museum said *"this device was mounted with a system which has the visit pathway for the most remarkable antiques in the Egyptian museum. This system includes information about 200 pieces"*. Normally, visitors receive the device with a headphone, and it includes a screen that presents audio files about antiques accompanied with text explanations relevant to the piece.

However, it was an outstanding enhancement to the guiding methods, given that the procedures of renting the device were too complicated. This can potentially waste an hour from the planned time of the visit. Then, unfortunately, due to managerial problems, the service of renting stopped working. The former director explained the reason as follows: *"We found that giving our employees part-time* *work was more expensive than the service of lending devices; therefore, the service stopped".*

Interestingly, local visitors did not show interest in this device, however, it was affordable to them, as the former director stated. The researcher attempted to ascertain the reason for not showing any interest in the device, but there was insufficient information to reveal the reason. There are some assumptions about this phenomenon, and one of them might be the reason:

A. It might not be affordable to local visitors.

B. The service may not have been adequately announced, so the local visitors may consider the digital guide service to be for international visitors only. After questioning some curators in the museum about the digital guide service, they stated that the service was advertised in English, not in Arabic. Therefore, the marketing message did not arrive properly.

Theme 5: Potential of Headset guides

After demonstrating the headset devices that employ AR/MR technology, some respondents emphasised certain points. These points might encourage the chance of using headsets in museums during touring.

A. If renting the device is affordable, visitors can significantly consider it among other guide methods.

B. If the technology can share the visuals that are supposed to be seen by the headset, visitors will admire it. The social factor is an essential factor during touring as people like to talk and share their knowledge.

C. Currently, at this stage, it might fit the public figures, who can afford the renting expenses. Perhaps, afterwards the technology will be more familiar, then became cheaper, and all visitors can afford to rent it.

D. Technological admiration is a key factor for accepting the method during tours. In other words, if people like the technology given, this can increase the potential of considering it.

Interestingly, three respondents, including the former director, considered the headset to be a good solution for guidance since it can partially overcome the problems associated with human guides.

3.5.7 Analysis Conclusions

The analysis manifested many sides of the research problem; some relevant experiments and pros, cons and the potential for some solutions are addressed in the next section.

1- The problems of current guided methods.

   The findings widened the scope of the tour guide problems and revealed some insights. These drawbacks could affect negatively on the visitors' museum experience and their overall satisfaction with the service. Also, these drawbacks can open the gates for proposing potential solutions that can overcome these problems with technological alternatives, and that is what this study aims to.

2- The literature of previous guide methods

   The findings revealed the previous experience of deploying an audio guide, and the analysis revealed the reasons behind not utilising it by local visitors. Furthermore, the findings were beneficial to the research by spotting the drawbacks of deploying the system in the museum. It also revealed some characteristics of the visitor, who might be interested in these such devices and technologies in order to consider his/her needs in the proposed system.

3- The potential for embracing augmented/mixed reality technology

   The interviewees showed positive impressions of the suggested guided methods, which is considered a green light for the researcher to propose effective solutions. These solutions should carefully consider what the existing local and international visitor requirements are that were revealed in the observation study. The potential for employing AR/MR technologies is extended to make visitors wear MR headsets in their museum tours.

3.6 Restating the problem

After revealing all of the problems found in the exploratory study, certain problems are inevitable and out of the focus of the researcher, such as drawbacks in the museum management. However, the problems sought to be tackled in this research are discussed in the following sections, accompanied by proposed solutions.

(Problem 1) Role of the Guide: The museum suffers from a lack of guided methods. The only guide method available is a human tour guide. This method has many advantages and is preferable for some visitors, although others found it expensive, with several drawbacks. There are no other guide tools or gadgets available to use, especially for local visitors.

– Proposed solution: This research seeks to find an effective substitute for touristic guidance by defining a new guide approach that deploys an augmented/ reality headset application. The expected touristic experience should be intuitive, immersive and help the visitor grasp more information about the context of the museum and to have the privilege of being independent. It also attempts to overcome the other problems encountered in the current guide method, which were revealed in the preliminary studies. Moreover, it should be engaging, attractive to visitors, and could change the whole experience of visiting museums.

(Problem 2) Enjoyment: The observation results showed a lack of engagement since the time spent in front of antiques is lower than normal. That phenomena influence the total time spent in the museum. Enjoyment is an intrinsic motivation for museum visitors that positively influence the level of engagement (Xie et al., 2008). Moreover, others can see that museum engagement is part of the enjoyment of the experience (Lin and Gregor, 2006).

– Proposed solution: The virtual guide system proposed earlier aims to entertain museum visitors and amuse them enough to increase the level of engagement which can reflect on the time spent in front of exhibited antiques. Increasing the level of engagement can enhance respectively on the holistic museum experience (Taheri et al., 2014).

(Problem 3) Usefulness: Acquiring information in museums for guided tours is limited by the information that the tour guide disseminates. However, the tour guide can answer some questions, but they are limited by the tour guide's knowledge. The museum has a lack of information sources regarding each exhibited item which reflects the level of usefulness the visitor desires to obtain.

– Proposed solution: The proposed virtual guide can unlock different sources of information, either visual (text, images, and videos) or audio and provides it intuitively. This method can make the visitor more independent and simplify access to information in order to acquire more knowledge and increase the level of usefulness of the tour visits.

(Problem 4) Sustainability of using guided tools: The only guided method used in the targeted museum was an audio guide, and it could not be sustained. Moreover, the visitors showed little interest after using it formerly.

– Proposed solution: The proposed virtual guide is concerned with this problem and it is designed in order to consider this aspect and ensure the continued use of it in the future and also avoid it being neglected like the audio guide mentioned earlier.

3.7 Summary

This chapter demonstrates the exploratory studies that have been conducted at the Egyptian Museum. These studies gave the researcher a closer look at the actual problems of the museum regarding the existing guiding services and visitors' behaviours. The exploratory studies were comprised of interviews and observations that led to synthesising the research hypotheses. These hypotheses aid the researcher to identify the best solutions to the problems clarified.

Chapter 4:
Methodology for System Design and Evaluation

4.1 Introduction

This chapter draws the roadmap for the research journey. It determines the required activities and procedures to answer the raised research questions. It also demonstrates how the design process (artefact) was constructed and evaluated using multiple techniques. It starts by focusing on the research methodology adopted, which could accomplish the research aims and objectives, which involves determining the philosophical stance for the present research. Then, it identifies the approach, strategy and suitable methods. The research methodology demonstrates several stages of the study as follows. The 'exploratory study' involves a solid understanding of the key factors of the research problem in the targeted museum (chapter 3). The following stage is 'descriptive study', which focuses on identifying the factors and proposes the MR system as a solution. Finally, the last stage is the 'Explanatory Study', which focuses on assessing the proposed system and assessing the influences of this system on the factors that need to be changed based on the research objectives. Furthermore, the explanatory study sheds light on the causal relationships among the variables.

The evaluation process and experiment design are also discussed in this chapter, including involvements of museum participants, actions performed and practical procedures in the museum atmosphere. The rationale of using specific data collection method was discussed in this chapter accompanied with relevant museum guides' projects. Furthermore, the planned evaluation was tested and approved before the on-site practical evaluation.

4.2 Research Paradigm

This study adopted Design Science Research (DSR), as the philosophical paradigm (Vaishnavi and Kuechler, 2004) that can determine the ontological, epistemological, methodological and axiological stance for changing the museum experience using immersive systems in museums. To clarify the research philosophy, table 4.1 demonstrates the most common paradigms such as the positivist and interpretivist paradigms against DSR, entailing the basic beliefs and various different positions.

Table 4.1 The Research Paradigms in information systems (Vaishnavi and Kuechler, 2004)

Research Paradigms			
Basic Belief	Positivist	Interpretivist	DSR
Ontology	A single reality, knowledge, probabilistic	Multiple realities, socially constructed	Multiple, contextually situated alternative world-states, socio-technologically enabled
Epistemology	Objective, dispassionate, detached observer of truth	Subjective (i.e., values and knowledge emerge from the researcher participant interaction)	Knowing through making: objectively constrained construction within a context Iterative circumscription reveals meaning
Methodology	Observation, quantitative, statistical	Participation, qualitative, hermeneutical, dialectical	Developmental, measure artefactual impacts on the composite system
Axiology	Truth: universal and beautiful; prediction	Understanding: situated and description	Control; creation; progress (i.e., improvement); understanding

After the demonstration of the different research paradigms that are commonly used in information systems, and based on the raised research questions investigated in this study, the design science research paradigm is considered most fitting. This study aims to design and develop a virtual guide using the mixed reality system to enhance the visitors' museum experience. This study also constructs a new form of guidance in museums, which was characterised in chapter one. Therefore, the aim to change the museum experience and the form of guidance involves the development of an artefact. Thus, adopting the design science research paradigm can draw the map for using the appropriate methods, approaches and activities related in order to achieve the desired artefact.

4.3 Design Science Research Methodology

The methodology adopted in this project is the Design Science Research (DSR) methodology (Hevner and Chatterjee, 2010) since this study aims to design a new artefact for developing a new mixed reality system. Design science works by finding new solutions to unsolved problems or demonstrating more effective solutions to solved problems (March and Smith, 1995).

DSR has recently acquired the attention of Information Systems (IS) research (Al-Debei, 2010). As Vaishnavi and Kuechler (2004) stated, DSR involves two essential activities to enhance and understand the behaviour of certain aspects of IS: (1) Creating new knowledge by designing an innovative artefact; which is reflected in this study through the, *designing and development of a virtual guide system using mixed reality technology*; (2) an analysis of using the artefact and the influence of using it on real-life performance, which is reflected in this study; by the impact of using the MR system on museum visitors and the museum experience.

Hevner and Chatterjee (2010) demonstrated the guidelines of the activities that are required for conducting and evaluating an effective design science research as presented in table 4.2. By adopting these guidelines, (Guideline 1) is concerned with designing the virtual guide system with mixed reality technology.

(Guideline 2) articulates the lack of engagement and the challenges of the guided methods in the targeted museum. (Guideline 3) is concerned with the proposed solution is being evaluated. (Guideline 4) involves the novelty of the system design process and the information visualisation concept introduced. (Guideline 5) the evaluated solution that has proven its efficiency for the stated problem by enhancing engagement and museum experience. (Guideline 6) the proposed solution that was iterated and developed based on the participants' feedback that was acquired from the pilot study. (Guideline 7) the study provides a clear demonstration of designing the system for immersive systems designers and researchers involving detailed demonstrations of the different design phases.

Designing an artefact according to (Gregor and Hevner, 2013, Mokyr, 2002) involves two different categories; *descriptive* and *prescriptive*. *Descriptive* artefacts are generated due to looking for truth through patterns, principles and theories. On the contrary, *Prescriptive* artefacts are used to accomplish a purpose or goal. Since this study is designing an artefact, it is categorised as a *prescriptive* artefact, as it involves technological rules and museum touring interventions. The *prescriptive* artefacts are divided into five types according to Gregor and Hevner (2013):

Table 4.2 Guidelines for Design Science Research (Hevner and Chatterjee, 2010)

Guidelines	Description
1. Design as an artefact	Producing a viable and identifiable artefact.
2. Problem relevance	Developing technology-based solutions to the relevant and important problems.
3. Design evaluation	A rigorous demonstration of the utility, quality, and efficiency of the designed artefact through the conducted evaluation method.
4. Research contributions	Effective DSR should provide a verified, clear and well-defined contribution to knowledge. The contribution could be achieved through the generality, novelty and the significance of the designed artefacts.

5. Design rigour	Rigorous methods must be applied in DSR particularly in the development and the evaluation of the designed artefact.
6. Design as a research process	DSR should address the research problem in the cycle of the problem-solving process until reaching the desired solution.
7. Communication of research	DSR should present the results effectively to both academic audiences, a technology-oriented audience and satisfying the needs of the professional audiences.

Constructs: This research demonstrates concepts in virtual guidance and a sense of immersion in mixed reality. This study also explains some relevant constructs relevant to museum engagement and also to the holistic museum experience.

Models: This type is concerned with defining the research problem and justifying the solution. This study produces a theoretical model for tackling the research problem.

Methods: This aspect consists of the techniques and algorithms that have been used in creating spatial mapping and human interaction using Microsoft HoloLens.

Instantiations: MuseumEye, as a mixed reality system is considered an instantiation as it is a practical system that can be utilised in different museums and can be introduced as a product.

Design Theory: This describes the forms, functions and principles that lead to developing an artefact.

4.4 Research Journey and DSR Process Model

In this section, the research journey is demonstrated and mapped to the DSR process model created by Hevner and Chatterjee (2010) and also mapped to the main outputs that result in each stage. This is depicted in Figure 4.1

Awareness of the problem: This stage represents the exploratory study that was conducted in chapter 3. After the literature review in chapter 2, the research problem was unclear, since information about regular visits, level of engagement and guide methods in the Egyptian museum was insufficient. So, for clearer, better verified and sufficient information about the research problem, the exploratory study involved some data collection methods, such as observations and interviews. The observation was used to investigate the time spent next to exhibited items to measure the level of engagement in museums. Interviews were used to investigate the guided methods in the museum and to reveal information about museum visitors. These methods were followed by relevant phases, such as data analysis until the factual problems of the research field could be crystallised. This stage results in the research proposal.

Suggestion: This stage addresses the research hypothesises. These outputs of this stage are the tentative design.

Development: This stage creates the research artefact, which involves designing the mixed reality system for guidance in museums using Microsoft HoloLens. Also, it introduces a new form of guidance in museums, known as a 'virtual guide'.

Evaluation: This stage uses the assessment methods to measure the performance of the system in the museum visitors. Observation was induced to measure the time expended due to using the system as a medium and a virtual guide during the museum tours. Questionnaires were used to evaluate the system aspects or constructs (research hypothesis), which make the system sufficiently effective to solve the stated problem. The evaluation was also conducted for a group of experts in the museums, information systems and human-computer studies. This stage is considered part of the explanatory study.

Conclusion: This section includes an analysis of the assessment results. It ends by discussing the contributions to a framework. This stage is a part of the explanatory study.

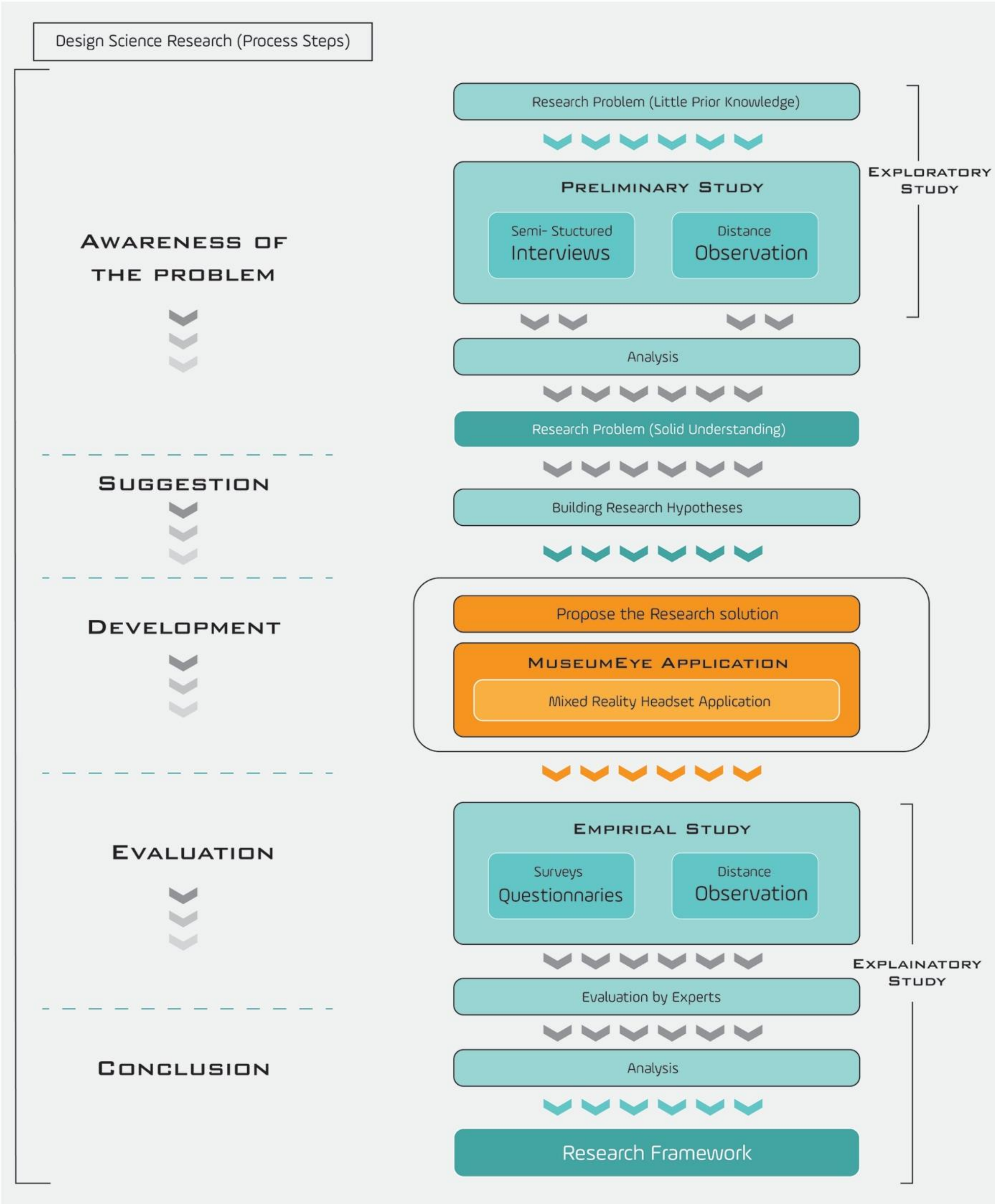

Figure 4.1 The Research Design

Design science research involves relevant research activities, such as design practice and action research (Swann, 2002). This study conducted design science research for producing knowledge based on research practices since this study demonstrated building an application that works as a solution to an existing problem. However, it is not limited to practical design, as it also provides a broader application to knowledge to other fields with related problems. MuseumEye is designed to engage visitors in the Egyptian Museum in Cairo in a highly immersive experience. This application can be broadly applied to other museums, galleries or any form of guidance. Thus, this study provides a contribution that makes it design science research and it is not limited to design practice.

4.5 Research Methods

Quantitative research usually involves numeric types of data that might be extracted from graphs or statistics. On the other hand, qualitative research involves non-numeric data, which might be taken from interviews or observations (Saunders, 2011). Quantitative research is much more closely related to testing theories than qualitative research since qualitative research is relevant to building theories. Moreover, the latter, which uses methods to reveal unobservable effects, is required to be measured in this study (Dasgupta, 2015).

The research methods employed in this study are *Mixed Methods*. As with the exploratory study, qualitative research was adopted in particular using interviews and observations for exploring the museum and getting a better understanding of the phenomena. Then, the qualitative tools were adopted again, such as through observation in order to measure engagement levels in the museum rooms during the use of MuseumEye. Quantitative methods were also employed in this study to evaluate the designed system, test the hypothesis, and investigate the effectiveness of the role of the guide, as it was proposed as a solution for the research problems.

Concerning the time horizons, this research will undertake a cross-sectional study to monitor the effects in a limited time. Due to time constraints, this research will not employ a longitudinal study (Saunders, 2011).

4.6 The System Evaluation Process – Definition

The aim of conducting the evaluation is to ensure that the system could solve the problem revealed in the exploratory study and also measure how the system is sufficiently beneficial to guide visitors in museums.

4.6.1 CONTENT – What is being evaluated?

According to the research objectives, the research is required to assess the museum system using different methods: qualitative and quantitative tools, as depicted in Figure 4.2. Observation tools are used to measure engagement by calculating the time spent in front of the exhibited antiques during the use of MuseumEye, and also to observe the visitors' behaviour and responses. The questionnaires are designed to tackle the raised problems revealed in the exploratory study and also assess the designed system through certain aspects that are relevant to the technological side and the human/social side. Also, the questionnaires are designed for two groups of users: the museum visitors (participants) and the museum professionals and curators (experts).

4.6.2 Surveys/ Questionnaires

This instrument was established for the technologists, and it consists of measures that were developed from standard instruments, such as the Likert Scale (Kaplan and Duchon, 1988). The surveys are designed to measure the perceived changes, concerns and expectations of the information system (Kjerulff et al., 1982). An evaluation using questionnaires was conducted to investigate and measure some aspects through two groups; (Group 1) Participants or daily visitors and (Group 2) Museum practitioners, experts and academic experts.

The measures that needed to be evaluated are divided into two categories: Social constructs and technical constructs.

Firstly, the 'social' constructs are adopted from the research problems revealed by the exploratory studies that were conducted in chapter 3. Thus, these questionnaires are employed to assess these constructs after using this system.

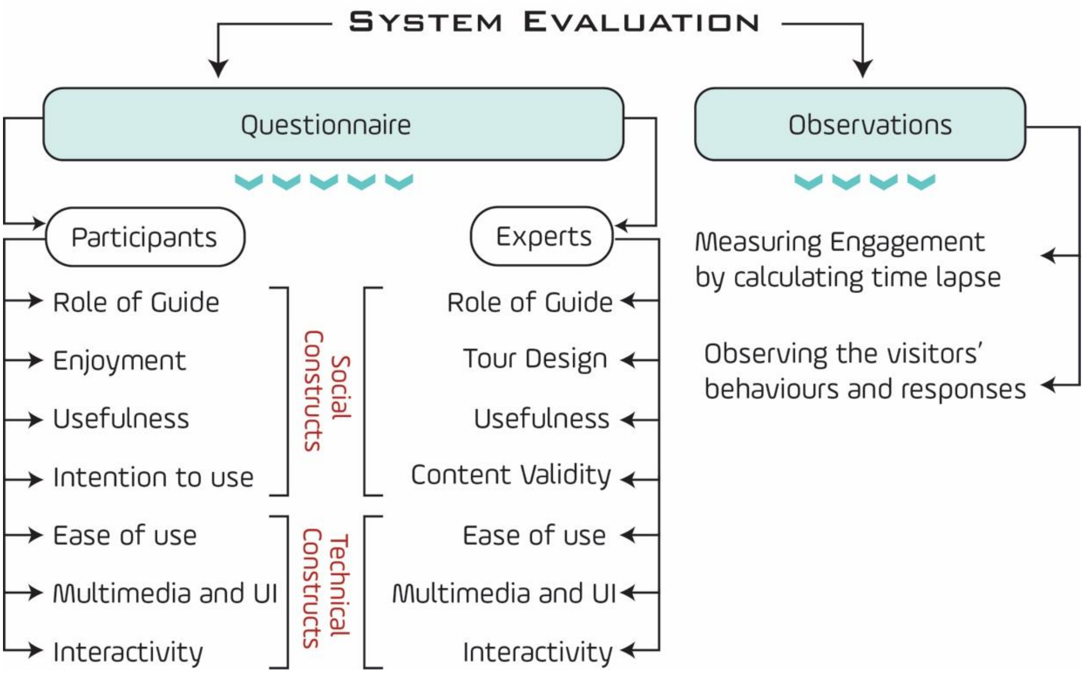

Figure 4.2 System evaluation content 4.8.2 Surveys / Questionnaires

1- Role of the guide (Participants / Experts): Due to tackling the research problem and also introducing a new form of guidance in museums to enhance the engagement and the museum experience, this construct is being measured in the system evaluation. Also, the fundamental function of MuseumEye is to work as a guide for visitors, especially domestic visitors who experience a lack of tour guides – as discussed in chapter 3. This aspect measures whether MuseumEye, as a virtual guide, can perform the role of guiding successfully, or if it cannot compensate for the absence of the human tour guide or take their place as an optional tool of guidance. It also measures the effectiveness of disseminating the information required and helps the visitor to explore and discover the exhibited items.

2- Enjoyment (Participants): As discussed in chapter 3, lack of enjoyment was an obvious phenomenon during the daily tour visits. MuseumEye aims to bring amusement and pleasure to visitors throughout the dissemination of information via storytelling and narratives. Visitors (as users) prefer to be active users, not passive listeners, so they prefer interaction as much as possible. Based on the design of MuseumEye, the system is sufficiently interactive to make the visitor interested enough. Hence, the evaluation of this aspect is crucial to the evaluation process because if the system is boring, it will be neglected in the future. Enjoyment as a construct has been measured in many museum systems (Hughes et al., 2005) (Sylaiou et al., 2010, Schmalstieg and Wagner, 2007).

3- Usefulness (Participants / Experts): MuseumEye supposed to transfer knowledge and enrich the contextual information of the exhibit. Moreover, it attempts to change the mental image of the ancient Egyptian civilisation. Therefore, it was necessary to measure this aspect after using the system, especially after demonstrating the problem of acquiring knowledge from the museum in the traditional visit – in Chapter 3. Usefulness has been exploited in many museum studies as a construct to be assessed (Hughes et al., 2005, Haugstvedt and Krogstie, 2012, Wojciechowski and Cellary, 2013).

4- Intention to use (Participants): This construct is measured to assess the sustainability of using the system in the museum after the experiment is induced. This is due to the fact that the previous guide tool was employed in the museum and visitors stopped using at after offering it for public usage. Several museum studies have employed this construct (Wojciechowski and Cellary, 2013, Lee et al., 2015, Yilmaz, 2016).

5- Tour design (Experts): This construct measures the chosen route in terms of whether it is sensible for the thematic tour or contradicts the tour's logical sequence. This aspect also needs to be evaluated by museum experts as it is usually formed by tour guides and curators. Tour design was identified earlier by museum practitioners (Moscardo, 1996, Mayaka and King, 2002) (Karoulis et al., 2006).

6- Content validity (Experts): One of the evaluation goals is to validate the content by museum experts/archaeologists/curators. This construct also measures the clarity and understanding of the content. It also ensures the content delivery and its adaptability to visitors' various educational backgrounds. The content has been measured before in several studies

(Carrozzino and Bergamasco, 2010) (Vlahakis et al., 2001) (Bellotti et al., 2002).

Secondly, technical constructs are required to identify the technical aspects that need to be explored in the system. Table 4.3 encompasses the literature of the previous system that was applied and evaluated in museums in terms of indicating the aspects that were measured. Although some technologies in the literature were different from HoloLens-based immersive MR, these aspects still needed to be explored.

Table 4.3 Previous studies and the explored aspects in museums

Projects/Studies	Museum/ Location	Technology - Device	Evaluation Aspects
(Damala et al., 2008)	Museum of Fine Arts in Rennes, France.	AR – Mobile device	• Ease of use • Navigation • Content quality: audio and multimedia
ARCO (Karoulis et al., 2006)	Victoria and Albert Museum and SussexPast, UK	Virtual Museum and AR – Mobile and website or kiosks	• Usability • Content: terminology suitability, logical order • Reliability • Multimedia
ARCHEOGUIDE (Vlahakis et al., 2001)	The archaeological site of Olympia, Greece.	AR – Mobile units (laptop, pen-PC, palmtop-based)	• Ease of use • User satisfaction • Multimedia • User Interface • Content • Willingness of future use
Trondheim historical streets (Haugstvedt and Krogstie, 2012)	Trondheim historical streets, Norway	AR – Mobile device	• Usefulness • Ease of use • Enjoyment • Behaviour attention
Hypermedia Tour Guide (Bellotti et al., 2002)	Genoa's Costa Aquarium museum, Italy	Handheld guide - palmtop computer	• Usability • Information presentation • User satisfaction • Content

MR Sea Creatures experience (Hughes et al., 2005)	the Orlando Science Center's DinoDigs exhibition hall, USA	MR experience - video see-through HMD	• User reactions • Usefulness • Enjoyment • Willingness of future use
Agent *Max* (Kopp et al., 2005)	The Nixdorf Museum	AI (artificial Inelegance) – Flat Screen	• Interactivity
ARCO (Sylaiou et al., 2010)	Victoria and Albert Museum and SussexPast, UK	Virtual Museum and AR – Mobile and website or kiosks	• Enjoyment • Previous computing experience • User satisfaction
(Carrozzino and Bergamasco, 2010)	*the Virtual Museum of Sculpture* (*VMS*) of Pietrasanta	Virtual Museum – VR gadgets	• Interactivity • Immersion • Content

The most common factors that can represent the technical aspects of MuseumEye are:

1- Multimedia and UI (Participants / Experts): This aspect measures the content design - it is comprised of video and audio documentaries and informative images, examined from an aesthetical and design perspective (Karoulis et al., 2006). In addition to measuring the user interface from the way it looks and how it assisted the user in grasping the information needed, this aspect also measures the way the virtual guide looks and its performance during the demonstration. It also extends to evaluating the 3D models of the surrounding guards and gods from a graphical perspective, along with their customs and how they represent the exhibited context to make the experiment more immersive.

2- Ease of use (Participants / Experts): as Davis writes, this is *"the degree to which a person believes that using a particular system would be free of effort"* (Davis, 1989). It investigates the usability of the system and to what degree the user feels, comfortable especially in terms of their obligation to wear a device during the tour. Also, it investigates the user's ability to reach the function that triggers what the user expects to reach.

3- Interactivity (Participants/Experts): is defined as *"the user's capability of modifying the environment and receiving feedback for his/her actions"* (Carrozzino and Bergamasco, 2010). Due to the particular hand gesture that is required to accomplish the interaction in HoloLens, this aspect measures the ability to interact with the designed UI, as it is considered a new experience for users to face.

4.6.3 Theoretical Lens and Hypotheses Development

The questionnaire in this study does not only investigate the aforementioned constructs (measured by participants) in terms of whether the proposed system can meet the satisfaction point or not, it also investigates the 'Role of Guide' among the other constructs of the study and explores how it enhances them, particularly in this context. Moreover, it also explores how the guidance function can influence the behaviour of future use and achieve a sustainability of usage in museums. This section develops hypotheses based on the literature review in order to develop a theoretical explanatory model, as depicted in Figure 4.3.

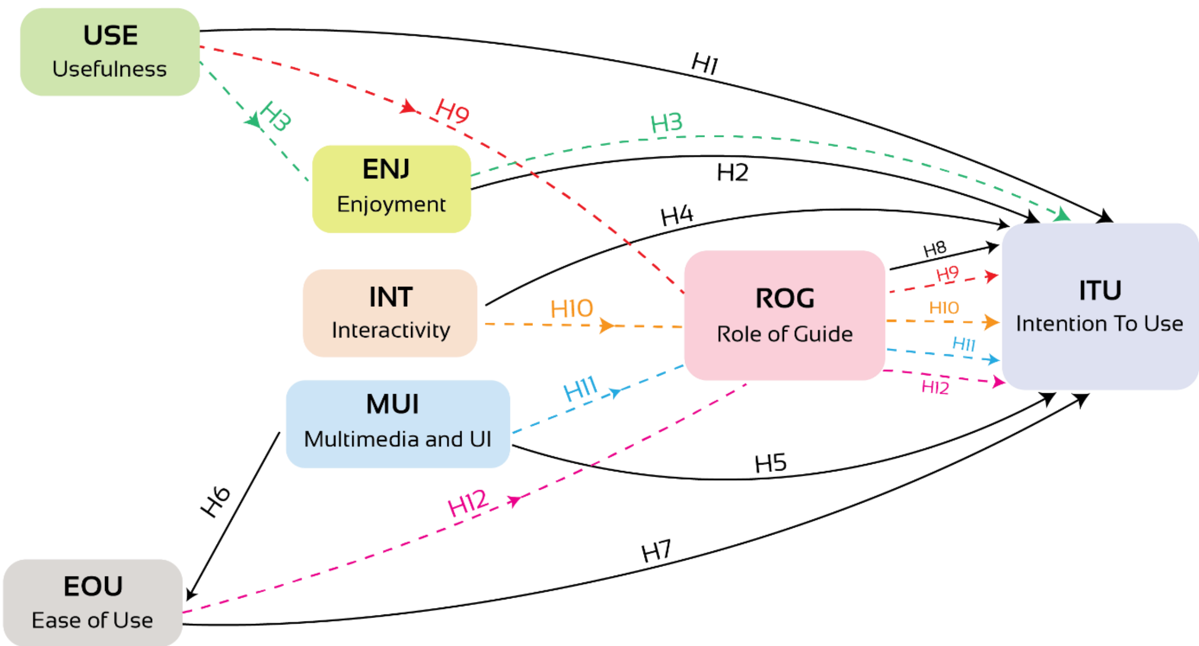

Figure 4.3 Proposed theoretical model

This conceptual model integrates the social and technical constructs with the Technology Acceptance Model (TAM), developed by Davis (1985) as both the perceived usefulness and perceived ease of use are considered cognitive responses, and intention to use is considered an effective response in TAM.

Usefulness (USF): is one of the fundamental factors to predict user acceptance by measuring the effect of behaviour usage (Davis, 1985, Davis, 1989). The perceived USF has a significant effect in the intention to use (ITU) in similar contexts (Lee et al., 2015, Haugstvedt and Krogstie, 2012, Chung et al., 2015).

H1: Usefulness (USF) has a significant direct relationship with intention to use (ITU) MuseumEye.

Enjoyment (ENJ): Empirically, perceived ENJ has a significant effect on the intention to use (ITU), since the joyfulness that users can feel after using the AR applications can motivate them to continue using the system in the future. Similar studies have demonstrated this relation (Lee et al., 2015, Haugstvedt and Krogstie, 2012, Wojciechowski and Cellary, 2013, Sylaiou et al., 2010, Leue and Jung, 2014). Enjoyment (ENJ), as intrinsic motivation, also has a significant effect on perceived usefulness (USF), which is considered an extrinsic motivation in a study that uses AR in a teaching context (Balog and Pribeanu, 2010).

H2: Enjoyment (ENJ) has a significant direct relationship with intention to use (ITU) MuseumEye.

H3: Enjoyment (ENJ) significantly mediates the relationship between usefulness (USF) and intention to use (ITU) MuseumEye.

Interactivity (INT): Once users interact with MuseumEye, they can experience two different types of interaction: human-computer interaction and interpersonal interaction. Human-computer interaction is derived from using the mixed reality system in the museum environment. Then, interpersonal interaction is a result of the interaction between the visitor and his/her peers. Interaction has shown an influence on intention to use (ITU) the IS (Liu et al., 2010).

H4: Interactivity (INT) has a significant direct relationship with

intention to use (ITU) MuseumEye.

Multimedia and UI (MUI): Good interface design and multimedia content can influence visitors to engage and grasp information, which then influences the perceived ease of use (EOU), and correspondingly, it can influence the intention to use (INT) the system in the future. Similar studies have proven the relationship between MUI and ITU (Hong et al., 2011). Other studies showed that multimedia and UI (MUI) also has a positive influence on the ease of use (EOU) of IS (Liu et al., 2010).

H5: Multimedia (MUI) has a significant direct relationship with intention to use (ITU).

H6: Multimedia (MUI) has a significant direct relationship with ease of use (EOU).

Ease of Use (EOU): According to (Davis, 1985, Davis, 1989), EOU is one of the essential factors that predicts user acceptance by measuring the effect of behaviour usage. EOU has a positive and significant influence in the intention to use (ITU) the construct in related contexts (Lee et al., 2015, Haugstvedt and Krogstie, 2012, Chung et al., 2015).

H7: Ease of Use (EOU) has a significant direct relationship with intention to use (ITU).

Role of Guide (ROG): This construct is created by this research as it introduced a new form of guidance using Mixed Reality and it applies essential roles that can guide visitors, such as exploring new venues, disseminating information, pathfinder, etc. So, the aim of the quantitative study is to investigate whether the role of the guide is achieved through MuseumEye and whether it has an influence on the intention to use (INT) in the future. This investigation can lead to establishing whether this system can remain in the museum or not after being experimented on.

H8: Role of guide (ROG) has a significant direct relationship with intention to use (ITU).

Here, the hypothesis investigates how the perceived usefulness (USF) of using MuseumEye can influence satisfaction with the guidance service that the user can get, which can correspondingly affect the intention to use (ITU) MuseumEye. So, this investigation examines whether the role of the guide (ROG) can cause a significant influence if it mediates usefulness (USF) and the intention to use (ITU), as it has previously hypothesised the two constructs directly.

H9: Role of guide (ROG) significantly mediates the relationship between usefulness (USF) and intention to use (ITU).

This hypothesis investigates whether interactivity (INT) can enhance the satisfaction of being guided (ROG) by the MuseumEye system and then it can positively motivate visitors to continue using it (ITU) in the future. As in H4, it was hypothesised that there would be an influence of interactivity (INT) on the intention to use (ITU).

H10: Role of guide (ROG) significantly mediates the relationship between interactivity (INT) and intention to use (ITU).

As previously hypothesised in H5, multimedia and UI (MUI) has an influence on intention to use (ITU). This hypothesis investigates whether good multimedia and UI can boost the satisfaction of being guided and if it achieves the desired role of guide (ROG), which can then correspondingly influence intention to use (ITU).

H11: Role of guide (ROG) significantly mediates the relationship between multimedia and UI (MUI) and the intention to use (ITU).

This hypothesis investigates whether the ease of using the system (EOU) can motivate the user to be guided (ROG) by MuseumEye, wherein it can then motivate the user to continue using the system in the future (ITU). This assumption was built based on the hypothesis of H7, which considers how ease of use (EOU) influences the intention to use (ITU).

H12: Role of guide (ROG) significantly mediates the relationship between ease of use (EOU) and intention to use (ITU).

4.6.4 Survey/Questionnaire Design

Firstly, the participant questionnaires are designed to include 5 main parts, starting with a welcome page and a consent form, then four other sections that are designed to explore the factors mentioned earlier. The questionnaire was designed to include 35 questions with the 5-Likert scale to rate the responses, where 1 = strongly disagree and 5 = strongly agree since similar studies have also employed it (Hughes et al., 2005). It took between 8-10 minutes to be completed. The questionnaires were designed based on the Questionnaire for User Interface Satisfaction (QUIS), which assesses user satisfaction with the system according to the interface and the usability aspects (Chin et al., 1988). The last two questions are considered an open space for visitors to write positive and negative responses to MuseumEye. The questionnaires are then translated into the Arabic language to be easier to read for local visitors.

Secondly, the expert questionnaires were also designed based on 5-Likert scale, and include five sections with 35 items. The five sections investigate the seven constructs. However, in this questionnaire, every question has a blank space for adding comments in order to open the space for experts to add unexpected responses.

Both questionnaires were piloted by a number of academic students and staff to ensure the clarity of the questions and establish whether they are easy to understand. Their feedback was taken into consideration, particularly when some mistakes were spotted. The ethical form was issued, and the questionnaires were also approved by the ministry of antiquities in Egypt and the museum management staff.

4.6.5 Sampling and Recruiting Participants

A promotional video of the MuseumEye system was published on social media to invite local visitors to the Egyptian Museum in Cairo to experience the system during their normal tour. The experiment was considered an intervention to the regular visits by local visitors. As part of the museum's restrictions, the museum management prevented conducting the experiment with foreign visitors and limited it to Egyptian visitors only.

There are some particular methods that can be adopted while sampling the participants in this experiment in order to acquire the most accurate representative data about the system evaluation. One of the ideal methods for data collecting was to involve sampling visitors who have prior experience in using Microsoft HoloLens applications, so they can critically assess the system without being biased with the technology and its abilities. However, none of the users among the Egyptian museum visitors had experienced the Microsoft HoloLens before, so the assessment involved evaluating the device and its abilities in conjunction with the evaluation of MuseumEye.

The research employed experts to conduct a discrete evaluation on some of the aspects that were common to the participant evaluation and others that were relevant to their expertise. Similar studies follow this approach for the sake of adding more validity to the evaluation process (Karoulis et al., 2006). They are experts in different disciplines such as Human-Computer Interactions (HCI), visual communication and museum studies.

4.6.5.1 Demographic Considerations

Age: Some studies (Dean, 2002) pursued measuring the exposure of Information and Communication Technologies (ICTs) to children compared with adults. Younger audiences expect the computer system to be part of museum installations and prefer interactivity in education systems (Best, 2012). Hence, they might have a different perspective and different level of usability of skills than adults. Another assumption might take into consideration older audiences, often called ‘silver surfers’, who use computer software as a hobby and might be willing to use the museum systems (Owen et al., 2005). So, the age determined for the sampling - according to the ethics approval - was above 18 to 25, 26-40, and 41-60.

Gender: was considered for evaluation, with a view to exploring if there were any variances in using and adopting the technology between different genders. According to (Owen et al., 2005), it is commonly known that males adopt technologies faster than females. So, the evaluation aims to explore if this phenomenon occurs in the present study.

4.6.5.2 Sample Size

According to the previous museum studies that adopted questionnaires (see table 4.4), the sample intended to reach 200 participants as an adequate size. However, after discarding uncompleted questionnaire, there were 171 valid participants. The final sample size was equal to the study conducted by Rubino et al. (2013). This sample size also fits the analysis methods that have been adopted such as exploratory factor analysis (EFA) and confirmatory data analysis (CFA).

Table 4.4 Sample sizes of survey participants in similar studies

Projects/Studies	Museum/ Location	Sample Size
ARCO (Sylaiou et al., 2010)	Victoria and Albert Museum and SussexPast, UK	29
MPF (Carrozzino and Bergamasco, 2010)	*The Virtual Museum of Sculpture* (*VMS*) of Pietrasanta	50
CorfuAR (Kourouthanassis et al., 2015)	City of Corfu island in Greece	105
LOCUS (Liarokapis et al., 2008)	The Swiss National Park	87
Historical Tour Guide (Haugstvedt and Krogstie, 2012)	Trondheim historical streets, Norway	42 street questionnaires 200 web questionnaires
Hypermedia Tour Guide (Bellotti et al., 2002)	Genoa's Costa Aquarium museum, Italy	103
(Lanir et al., 2013)	Hecht museum - University of Haifa, Israel	251

MusA (Rubino et al., 2013)	The Palazzo Madama-Museo Civico d'Arte Antica, an ancient art museum and UNESCO-listed historic residence located in the city centre of Turin (Italy).	171

4.6.6 How is the evaluation to be carried out?

Similar studies (Owen et al., 2005) (Rubino et al., 2013) divided the evaluation phase into three stages to assess the usage of the system by the museum participants: pre-touring, during the tour and after touring. In this study, two phases of evaluation were utilised during touring and after-touring, as the questionnaire was filled after the tour. However, during the tour user, behaviours were observed and assessed.

User/Visitor – different knowledge of IT

The participants who were invited to the evaluation might have a different level of IT knowledge and the ability to deal with the technological device. However, the device is completely new for visitors, either because it is new hardware or software. The evaluation process expected different abilities to become accustomed to it, even after a discrete tutorial period. It is vital to embrace the user experience of the system, as it reflects the user's level of interest and engagement with the immersive experience. It also obstructs the flow of information that can be gained during the tour. Due to it being new technology, it was expected that most of the users have not used the device before and that they would be unfamiliar with the hand interactions.

4.7 Observation

Observation, as an evaluation method was used frequently in museum studies (Hooper-Greenhill, 2013). Systematic observation has been constantly conducted in museums for the last 20 years (Yalowitz and Bronnenkant, 2009). Timing and tracking studies were accepted as a valid and reliable method through the 1990s.

Serrell and Adams (1998) articulated studies of around 110 museums and exhibitions used timing and tracking for research conducted on visitor behaviour. This method is conducted by tracing the visitors' routes they take, following where they stop, what they actually do, where they look and measuring the time spent during those stops. Some studies integrated visitor tracking with observation and the tracking process, which is considered a discreet recording of visitor behaviour (Kelly, 2009). Tracking recordings can include the antiques that were visited. Also, it records other visitor's behaviour, such as reading, gazing or studying, and involves recording the pathways and the flow of tour and where the visitors stop or pause during the flow (Kelly, 2009) (Yalowitz and Bronnenkant, 2009). Nowadays, observation is considered an essential element of measuring the success of the exhibition; it is also a significant method for understanding the visitor experience (Yalowitz and Bronnenkant, 2009).

The aim of this observation is to extend the time the visitors spend in front of the exhibited items by using the proposed system, which was measured in the exploratory study in chapter 3. Similarly, some studies employed technologies to increase the time the visitor can spend in museums (Wang et al., 2009). This observation has another objective, which is observing visitors' behaviours and activities whilst wearing the HoloLens and using the MuseumEye system during their tour. Unexpected behaviours can interpret the non-intentional actions, which can provide more information about the museum experience than the questionnaires can provide. Also, it can justify some responses that participants will claim in the survey method.

4.7.1 Observer Stance

Based on the topology of the participant observation roles developed by Saunders (2011) – as depicted in Figure 4.4, the activity of observation in this stage took the stance of being an 'Observer as Participant'. This is due to the fact that the identity of the observer is revealed to the participant, and the participants were asked for permission to be filmed for the research sake. Also, the researcher is not part of the activity as his role is to merely observe the activity.

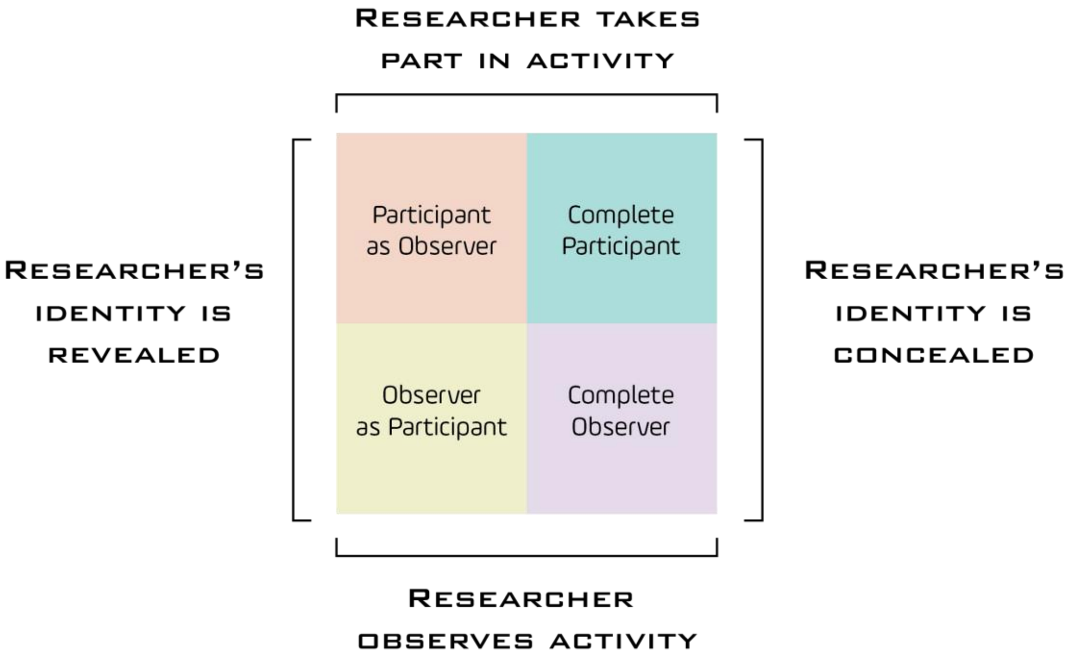

Figure 4.4 Topology of participant observation by Saunders (2011)

4.7.2 Observation Procedures

The observation method in this research uses time consumption as a quantitative unit to express interest in the museum experience. Similarly, some studies sought to create an experience that encourages longer visits and tours (Hughes et al., 2005) (Lanir et al., 2013). The next lines state the qualitative and quantitative parameters that are required by this research tool:

1- Time spent for storytelling scenes: the results of this variable are significant for the system's designer to measure the degree to which the storytelling was interesting enough to attract the visitor and keep him/her waiting to enjoy the stories. Also, it was important to identify which part of the system was interesting and extended the time of the tour more than others.

2- Time spent for exhibited items: This is the main desired finding that is needed for this research, as it will be compared with the results measured in the exploratory study (chapter 3). Also, it can identify the degree that interaction with the item's exploration technique was interesting to visitors and if it maintained their enjoyment. It is also helpful for the system designer to compare which part of the system was more enjoyable.

3- Time spent gazing at the virtual guide: This variable is beneficial to measure the impact of the guide's sense of presence.

4- Number of portal points activated by the participant: This variable can measure the sense of independence, the free will of touring and walking, and the agility of the system's usage continuation since if the users found complications with the system, this value could show lower numbers.

5- Nature of behaviour: This measurement is beneficial to reveal unexpected behaviours, which can either emphasise on the strength of the system engagement, or it can show the negative side of it. This exploration is a detailed interpretation of facial expressions that visitors can perform during the experiment.

6- Overall duration: This value can show the impact of the system in one single room in order to represent a different angle of the results as a holistic experience rather than a single item exploration.

4.7.3 The atmosphere of the museum experimentation and the observation activity

The observation activity covered two types of museum visitors: those who accepted the invitation of the experiment and those who volunteered to participate when they saw other visitors experience a new manner of touring. When the visitors arrived at the tour's starting point, they stood in front of the camera for ethical consent, then a short tutorial was demonstrated. Then, the participants are asked to start their tour via the auto loaded storytelling scenes, where they have the option to choose the interactive points that trigger the antique navigation scenes, as depicted in Figure 4.5.

The observation activity detected visitor activity in Tutankhamun's room via moving the camera and the notes that were taken. The outputs of the observations were analysed based on the quantitative aspects, which were measured by the time lapsed and the qualitative aspects that demonstrate the nature of the visitor’s performance during the tour These qualitative results can provide indications about the impact of the medium during the museum experience in terms of the engagement, enjoyability and level of immersion.

Figure 4.5 Photo shots from the observation activity

4.7.4 Lessons learnt during the observation

The main key point of the observation during the experiment was to capture the performance, count the time in the room and follow the participant’s navigation around the main ten scene portals and the three storytelling scenes. However, the location of the camera on the first day was quite far from the 10 scene portals, and the antiques were accidentally moved away from their old locations, so the observer kept zooming in to ensure performance coverage. Therefore, it was not easy to film the participants and get a closer look. For the following seven days the camera location was changed to obtain better filming quality.

The noisy environment and the crowdedness of the museum were disturbing and affecting the concentration of the museum experience. Consequently, many participants complained about the low audio volume from the headset. Therefore, in the following days, earphones were employed. The impact of using them was evident on their facial expressions and this also affected the tour duration.

The short tutorial that was given before the tour was very concise; the hand gestures were demonstrated by the researcher. Then, during observing the first group of participants, it was noticed that they were struggling to make the hand gestures correctly. Therefore, in the following days, the tutorial time expanded to provide practice for the upcoming participants to help them make the hand gestures correctly, which impacted the level of assistance requested. Also, the tutorials included some images from UI visuals of the MuseumEye to ease the interactions for further visits.

The battery life could work non-stoppable for 4 hours, which caused some delays in charging the device, as it kept turning off during visits. Therefore, in subsequent days, there was a greater organisation in terms of timing charging the devices and queuing participants based on battery life limitations.

4.8 Summary

The MuseumEye experiment was not an easy procedure, due to museum management and security restrictions. Despite the facilities they provided, there are some facilities that were not present, such as the waiting seats for the participants and there were insufficient electricity plugs for charging the devices. Also, the time given for the experiment was insufficient for hosting more participants, which affected the MuseumEye tours. The long queues for the participants caused pressure on the current participant to finish his/her tour and they often desired more time. They could extend it, but the experiment atmosphere implicitly informed the participant that he/she had to finish the tour once they were satisfied with the designed tour and once they had experienced the entire concept of the mixed reality tour. The next chapter discusses designing the MuseumEye system and the following chapter provides the results and the analysis of this experiment.

Chapter 5:
Design and Development of The MuseumEye

5.1 Introduction

This chapter focuses on the process of building MuseumEye, starting with the findings of the exploratory study, then feeding them to the system design process. This is followed by a vivid demonstration of the visual content that the application contains. It also illustrates the process of creating the visual content, and the process of overcoming the obstacles faced during these phases. The visual content is created, designed and then shows the way the headset is capable of storing and displaying these visuals.

5.2 The Aim of MuseumEye

The HoloLens-based application MuseumEye aims to prove the potential of using mixed reality as a guide to change the tourist experience in museums. This will be accomplished by creating a mixed reality experience, where visitors feel that they are experiencing a glimpse of the ancient age recreated in the museum. Adding virtual characters representing folk and environmental objects overlaid with music and sound effects will create a special mixed reality experience.

MuseumEye also introduces a virtual guide, who walks around, speaks to the visitor and provides them with various types of visual information, such as videos, images and 3D visualisations of the antique. The intention behind exploring the 3D virtual antique is to get a closer look at the antique outside of its glass box and draw the visitor's attention to its details. Also, it allows the user to see the antique from different angles and interact with the virtual replica.

5.3 The Workflow to Identify the Characteristics of MuseumEye

Before designing the system structure, it was important to identify the characteristics of the system and its requirements, core functions, supplementary functions and understand what the targeted museum visitor requires. Its primary role is to guide visitors in the museum context, and there are other additional roles for the system usage. These roles include approaching the visitors to walk on a thematic tour, gaining historical knowledge and entertaining them in a single comprehensive museum experience. So, in order to identify MuseumEye's characteristics, a workflow was introduced to gather the data required, as depicted in Figure 5.1.

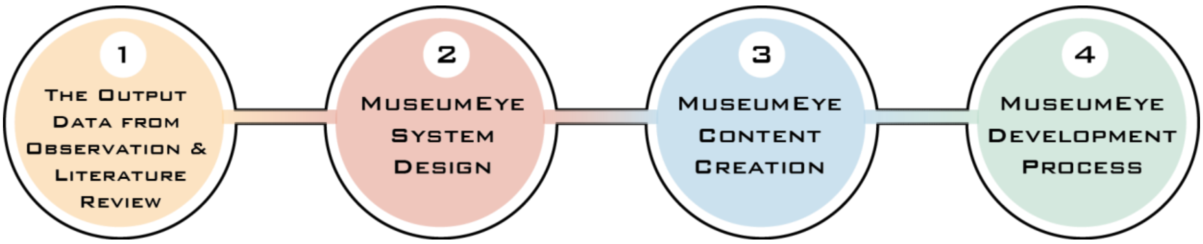

Figure 5.1 The workflow of building MuseumEye guiding system

5.4 Stage 1: The Output Data from Exploratory Study and Literature Review

After the review of the AR/MR guides in chapter 2, it was concluded that most of the essential functions that should exist in the system were concerned with emphasising the role of guiding, feeding historical knowledge, and entertaining the visitor. Moreover, the observation analysis (covered in chapter 3) of the exploratory study revealed some behaviour patterns that museum visitors perform during their visit. These behaviours added personalised features to the museum under study and the nature of its visitors, both of which should be considered during the system design phase of MuseumEye.

Pattern 1: Visitors tend to walk in groups, which can make the tour more interesting and consequently maximise the time spent in front/next to the exhibited item.

Pattern 2: Visitors using a guiding tool tend to spend more time in front/next to the exhibited item. Therefore, being guided with a tool can maximise the tour duration.

Pattern 3: Visitors who are in groups tend to read the labels of the items loudly.

Pattern 4: The tendency to take pictures and selfies was evident in many cases especially in the targeted room.

5.5 Stage 2: MuseumEye System Design

Building a mixed reality system, which combines physical environments and virtual objects, and requires a significant understanding of the realm's perception. This capability can give the user the ability to move, engage and interact with both worlds naturally. This can potentially surpass the abilities of previous AR mobile guides (Miyashita et al., 2008) (Damala, 2009) (Morrison et al., 2009) (Tillon et al., 2011) (Ghouaiel et al., 2017).

Moreover, an understanding of the physical environment from other headsets/smart glasses that have been previously been adopted as museum guides (Vlahakis et al., 2002) (Brondi et al., 2016) cannot be compared with a headset such as Microsoft HoloLens. Therefore, these capabilities unlock the limitations of spatial designs and open prospects to build live historical scenes that could be presented to the visitor in the same room. Furthermore, the hand gesture controls of the headset device enable the user to interact with the content and enrich the level of interactions. Thus, the visual content structure of

MuseumEye can involve creating walls, ground surfaces, interior objects and life-size human avatars.

5.5.1 List of MuseumEye Functions

For the sake of fulfilling all visitors' needs and accomplishing the museum guide's objectives, a comprehensive list of functions was formed. Some functions were adopted from previous mobile guide studies that were suitable for the nature of the system. Also, several other new functions were built to exploit the device's abilities and achieve the aim of the system.

Museum professionals were involved in discussing the proposed functions in order to evaluate them with respect to different museum exhibits. Also, software developers were invited to discuss the possibility of the proposed functions from a technical perspective.

The system functions vary according to their classification, which can define the particular action that the visitor performs while using the system. The categories were tackled as per the below descriptions.

1. Visual Communication: It is necessary to achieve direct communication between the visitor's senses and the system's visual and audio sources, as part of the immersive experience. So, a set of functions were designed to enrich the experience with various forms of communication during the tour.
2. Guidance: This involves a set of functions that involve visual and acoustical signs and cues, which guide the visitor around the museum room.
3. Interaction: This involves set of functions that utilise the headset's hand gestures to interact with spatial visuals. These functions aim to open up several ways of interaction between the visitor and the two realms.
4. Communication This is essential to create lines of communication between the visitor and the virtual guide to transfer knowledge and give instructions, using audio and visual clues.

Table 5.1 List of MuseumEye functions

Functions/Tasks	Description	Category	Purpose
Spatial scenery	Represents historical scenes composed of buildings, antiques and representations of characters – ancient Egyptian gods – considered to have spiritual power in ancient Egyptian culture. All of these virtual items will be mapped and superimposed on top of the physical room, including ceiling, walls and the floor.	Visual communication	Make the visitor fully immersed in both realms.
Virtual storyteller	Stories or narrative content were synthesised from reliable sources. This content is animated and presented by a virtual King Tutankhamun. The explanation is supplemented and synchronised by images, which are augmented with the guide points. The virtual Tutankhamun is life-size, and his way of acting is like a human guide.	Communication	Enrich the visitor with contextual information in an interesting manner. Providing the visitor with a customised guide so the visitor can listen and watch the explanation.
Labels and Scripts	A visible script triggered by the user	Guidance	It allows visitors to catch up with the ongoing explanation if part of it was missed. It provides an additional channel for visitors with hearing loss and an opportunity for multi-language extension.

Functions/Tasks	Description	Category	Purpose
Images	Augmented images activated by visitor hand interaction. These images represent the antique's condition when it was discovered. Moreover, these images were taken by the discoverer of the exhibited item.	Guidance	It enriches the content with different layers of visual information. Moreover, most of these images are not available to visitors. Showing these images while they are seeing the real antique is beneficial since it exposes visitors to in-depth visual information if they are interested in further exploration.
Audio narration	Audio commentaries by a narrator were produced from academic references in an interesting manner. They are synchronised with the displayed images that are referred to in the commentaries for further clarification.	Communication	This function is the essence of museum guidance, which is to listen to a guide and look at the antique simultaneously. It provides an effective response to one of the patterns observed among visitors, namely the tendency to read labels with loud voices. Therefore, this function is built to facilitate reading to others aesthetically.
Air tap / Hand interactions	Interaction – by hand gestures such as air tapping- is possible in several ways: - Moving between scene - Reveal the item's images - Reveal the item's script text - Use the UI navigation buttons - Spin or rotate the virtual replica of the item.	Interaction	Interactions can boost the level of engagement with visitors. As long as the user keeps interacting with the system, it means the information continues to feed into the user. Therefore, demanding information is a positive sign for knowledge retention.
Knowledge scale game	This is an interactive game for discovering secret and thrilling information about each antique. Around each	Interaction	This educational interaction is designed to improve user engagement and information retention.

Functions/Tasks	Description	Category	Purpose
	antique, there are small interactive circles, which reveal secret information next to them. It reveals this information by spinning the antique via hand gestures of the user's hands.		
Videos	An introductory and informative video about the museum collections and the particular collection exhibited is covered in the system.	Guidance	Watching videos during the experience will add diversity to the multimedia visuals. Videos have visual effects, text and images, and are created to be interesting for the visitor. Also, the visitor can skip the displayed video if he/she gets bored.
Scenes portal points	Based on the HoloLens' user location hotspots feature, MuseumEye provides interactive scene portals that are placed at key areas of interest. Once the user stands on top of it, it takes the visitor to the particular scene that is relevant to the item at that position.	Guidance	It is a direct and physical way to access scenes that include the particular guided methods, relevant to each exhibited antique. It is also part of the multi-scenarios design of the tour.
Orientation of Portal points	Auto-orientation occurs of the portal points that are capable of facing the visitor's position. Portal names will always face the visitor.	Visual Communication	Auto-orientation of the text is a fundamental ergonomic aspect of the system. The title of the scene informs the user of the name of the exhibited item if the user is at a distance from the item. It also provides access to the scene.

Functions/Tasks	Description	Category	Purpose
Taking a photo/ screenshot	The visitor can take a picture or screenshot of what he sees in MuseumEye using a voice command.	Communication	This function allows the user to capture and share what he/she sees to others. It is a response to the museum visitors' behaviour pattern, which was discovered in the observational analysis, namely the tendency to take photos (pattern 4)
Collaborative shared experience	This allows a group of visitors who wear the HoloLens headsets to see what the single visitor can see. It is a collaborative experience, which means all interactions are also possible for co-visitors who are in the same network connection.	Communication	This function encourages social interaction and opens prospects for opening discussion between the visitors. Hence, more interaction leads to gaining more knowledge about the context. This function was also built based on the visitors' patterns discussed earlier (pattern 1), namely that visitors tend to walk in groups and have conversations next to the exhibited antiques.
Animated characters	As part of the scene design, each character performs a particular animation to compose an epic and harmonic glimpse of the ancient Egyptian lifestyle.	Visual Communication	This results in a greater influence on the sense of immersion in the mixed realms environment.
Tap to place portals	This involves a hand gesture to interact with the scene portal and place them next to the relevant antiques. It is a protected function for museum curators who can access it through a combination of a keyword and a hand gesture. Also, 'tap to place'	Interaction	Working remotely with the museum guidance system did not make it easy to allocate the scene portals for the system creator. Once the system creator places these portals in the correct place, they will be allocated at these points forever. This function is

Functions/Tasks	Description	Category	Purpose
	is utilised when the scene opens in front of the physical item. It gives the user the possibility to place the scene wherever he/she wants.		also protected from the user, but not protected for the museum curators if they want to change the exhibited items' locations. Once the user accesses these scene portals, they would see an entire scene with a set of visuals that can facilitate the required guidance for the exhibited item.
Interactive virtual replica of an original item	Large-scale replicas of the authentic exhibited items were created to be displayed virtually next to the physical item. It is also interactive and allows the user to explore the virtual replica from different angles and observe details that are not possible to perform in the real museum.	Guidance/ Interaction	This partially adds the user's sense of controlling the object by 3D interaction, since the user controls the authentic item. Hence, visitors can rotate and move the virtual replica in lieu of physically touching it.
User Interface (Navigation and Controls)	It is a wide and curved user interface, which faces the user in the antique's scene, where the authentic item is placed next to the visitor.	Interaction	The user interface provides the user with various types of controls that lead to the growth of the visitor's interactions skills. It also provides the user with the freedom to enter or leave the scene whenever he/she wants.

5.5.2 Tour Design

Designing the desired tour is a significant part of the holistic system design process since it includes all exhibited antiques covered in the system. It identifies the walk cycle in the actual room of King Tutankhamun. It is essential in order to create a thematic tour that has the same context and common storytelling in an organised manner. However, for the sake of the research, it is preferable to use a loop shape in order to ease the process of testing and evaluating the system. This loop shape can ease the observational methods that the researcher will adopt to measure emotional and performance responses.

As Figure 5.2 demonstrates, the tour walk cycle starts and ends at the bottom of the figure. The tour consisted of three 'stations', which are marked with red points and nine 'stops', which are marked with black points. Red points represent the 'stations', which are defined as storytelling interventions that are allocated at the centre of the tour route. These stations cover general information about the king himself, his dynasty, who rules the country, the queen, old Egyptian gods, and battles, etc. The other scenes that are marked with black represent the exhibited antiques guidance scenes, which all have audio and visual guided methods. These are designed to be either sequentially or randomly visited. So, the visitor can go for the recommended sequence that is shown in Figure 5.2 or they can skip some stations. Thus, the content is not organised to be dependent on each other.

5.5.3 Spatial Mapping Design

The immersive experience must provide a sense of being surrounded by a virtual world. To make that happen, the physical environment is mapped with a virtual environment to provide two layers of all environmental elements. This means the visitor should see two ceilings, two grounds, two walls, etc. This concept is a prerequisite in order to make the visitor convinced of the virtual environment. If the ground is a bit higher than in reality, he/she might fall down due to confusion. Also, if the walls are not identically positioned, the visitor might be confused with the boundaries of the room. Therefore, this was recognised before initiating the system. The researcher measured the dimensions of the targeted room, 'The King Tutankhamun section', based on the existing plans of the floor. These dimensions were taken into consideration in order to spatially design the interior of the room and remap it on top of the physical room, as depicted in Figure 5.3.

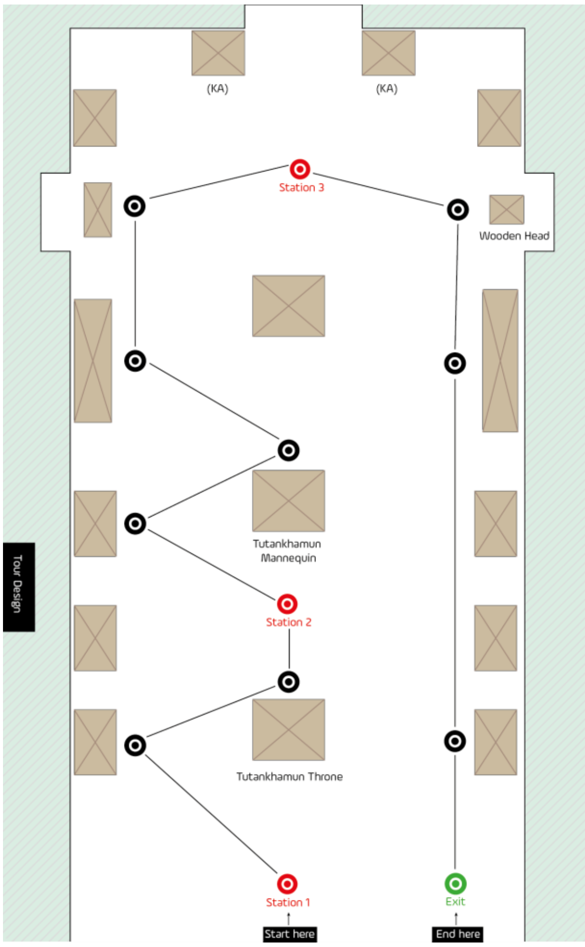

Figure 5.2 MuseumEye tour design

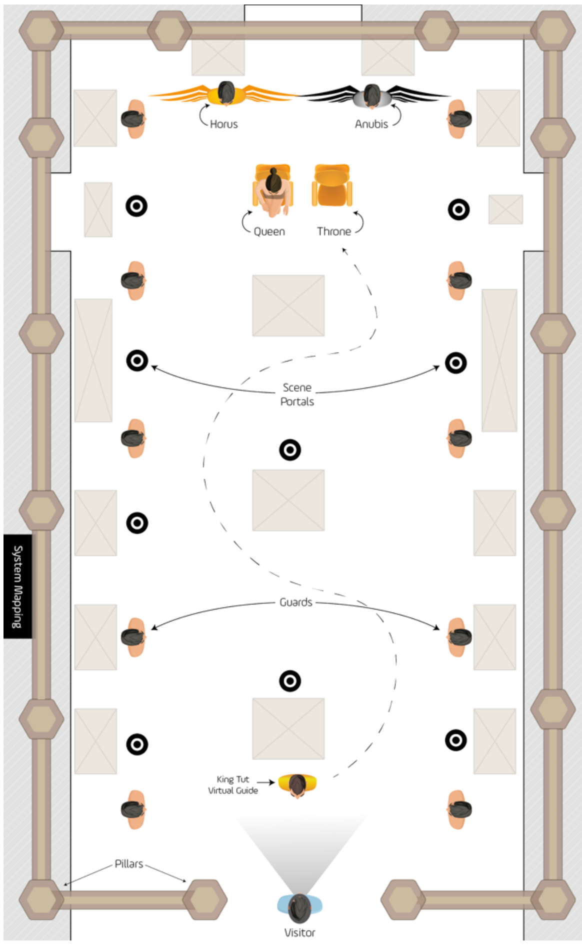

Figure 5.3 MuseumEye Mapping design

The above figure depicts one of the storytelling stations, 'Station 1', which represents how spatial mapping is achieved in the room of the king. Once the visitor stands on top of the interactive point, named 'Station 1', the scene is generated and mapped on top of the physical environment of the room. The virtual temple, which represents the place where the king used to rule the country, will replace the room walls. Moreover, the guards who protect the king stand at specific spots around the antiques. Empty spaces in the museum room are utilised carefully as the queen and the throne are placed by the far side of the room, surrounded by ancient Egyptian gods. The red and black dots represent interactive glowing points in the spatial design of the system, and once the visitor stands on top of them, they load a mixed reality scene based on the users' location. There are three red dots representing storytelling points where the king appears in front of the visitor and starts to tell his story with floating images that support the storytelling. In addition, there are ten black dots that represent nearby interactive points of the exhibited items.

5.5.4 Ambient Information Visualisation

Information visualisation can boost human cognition and can convey real-time information to individuals in public places (Skog et al., 2003). It is commonly defined as "*the use of computer-supported, interactive, visual representations of abstract data to amplify cognition*" (Card et al., 1999). Ambient visualisation is displayed on the surrounding environment or periphery of the user and it exceeds the limits of screens or desktop computers (Skog et al., 2003). However, ambient information can use the technology, which can move between the periphery and at the centre of the user's attention (Weiser and Brown, 1996). Therefore, ambient displays were implemented based on the physical environment and began to be exploited in public places (Skog et al., 2003).

Ambient information visualisation can potentially be used to immerse the museum visitor with the surrounding information (Hallnäs and Redström, 2002). Also, the ambient system can aid in reshaping museum experience with the presence of displays in museums (Boehner et al., 2005).

Since museums have been technologically developed, information visualisation has taken many forms to help interpret and communicate information visually to visitors. In the past, museums used to interpret their context visually through text labels and wall displays, which included printed posters and electronic displays. Then, museums moved a step forward, incorporating digital technology by embracing electronic displays, which were either static or interactive (Rocchi et al., 2004, Krüger et al., 2003), such as through smart tables. Information visualisation was reshaped by using artificial intelligence for interaction with visitors (Swartout et al., 2010). This study advances this concept in order to exploit the MR technology towards designing the surrounding visuals around the user. The notion of building the structure design of MuseumEye considers the visitor at the centre of the whole design.

This design consists of several layers of physical and virtual objects, in addition to a set of actions vital for communication and guidance. In order to avoid confusion due to the number of interactions and dispersed visuals, and further to allocate appropriate functions, the structure design of the system was created, as depicted in Figure 5.4.

The concept of the system is to communicate with the user through three layers, which are separated spatially. The first layer represents the user interaction controls and the user interface (UI) design itself, along with the user navigation controls. Logically speaking, the first layer should be spatially close to the visitor, so performing the hand gestures should be done accurately. Performing a click/air tap with Microsoft HoloLens requires three items: head movement as a pointer, gaze point as a virtual mouse, and hand gestures. So, by moving their head up, down, left and right, the user can aim the gaze point on top of the virtual button in the UI design layout to click and activate the function.

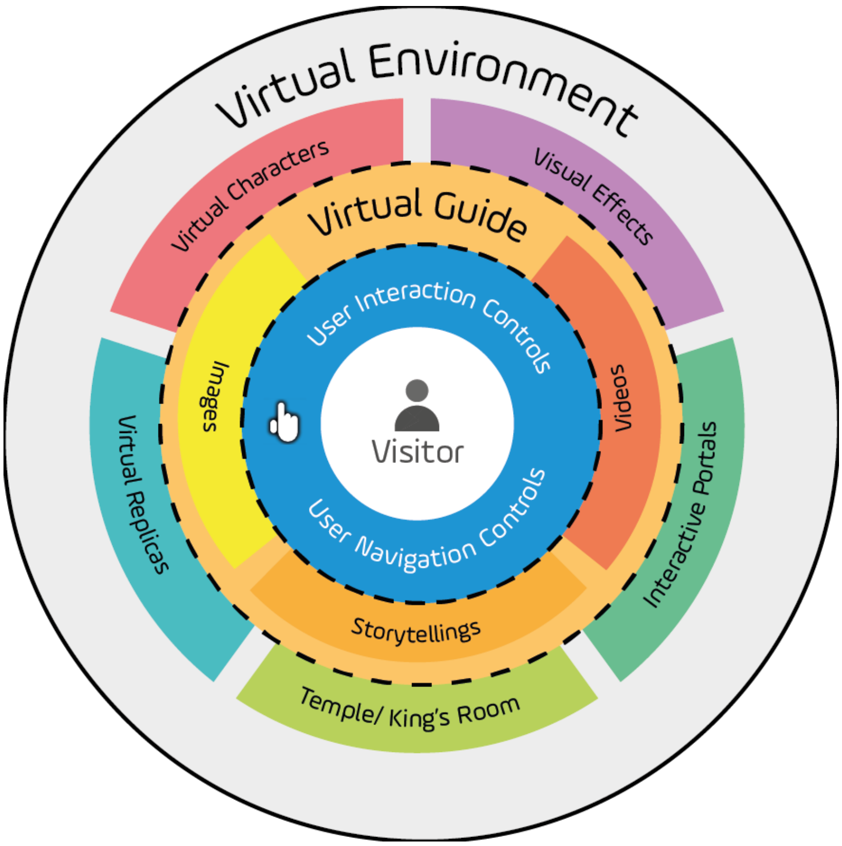

Figure 5.4 MuseumEye Ambient Information Visualisation design

5.6 Stage 3: MuseumEye Content Creation

Before going deeper into the structure of the content, it is important to identify the content types that Microsoft HoloLens can offer the user. The headset can present all types of visuals, which can take the form of images, videos, 3D audio and 3D holograms, which integrate with interactive hand gestures. Therefore, the next step is to employ the visual content, which fits with the function and is suitable for the guidance scenario in the guide system. Depicted in Figure 5.5 is the content design structure, which was built based on the concepts of human-centred design. The headset should be able to present visuals for the user who wears it. The subsequent sections explain each category of this structure.

5.6.1 3D Content Design

Holograms are 3D objects in space, so the designer is required to create 3D characters and environmental objects to create the elements of the virtual scene that helps to produce the intended guide system.

5.6.1.1 3D Characters

It is necessary to build the 3D characters that are relevant to the very context of the museum room. The room chosen for running this application has the properties of King Tutankhamun [c. 1346-1328 BC]. It is the same room that was chosen for the MuseumEye mobile application.

In order to offer more credibility to the system characters, it is essential to collate all the available information regarding King Tutankhamun and the Egyptians who lived in this period. Indeed, in the guided system, King Tutankhamun is the most significant asset due to being the main narrator of the system. He is supposed to replace the human guide in the guided system.

King Tutankhamun is considered the most famous Egyptian Pharaoh since when his tomb was discovered in 1922 it was almost entirely intact. His tomb was discovered by a British team led by the archaeologists Howard Carter and Lord Carnarvon (Barrow, 2013).

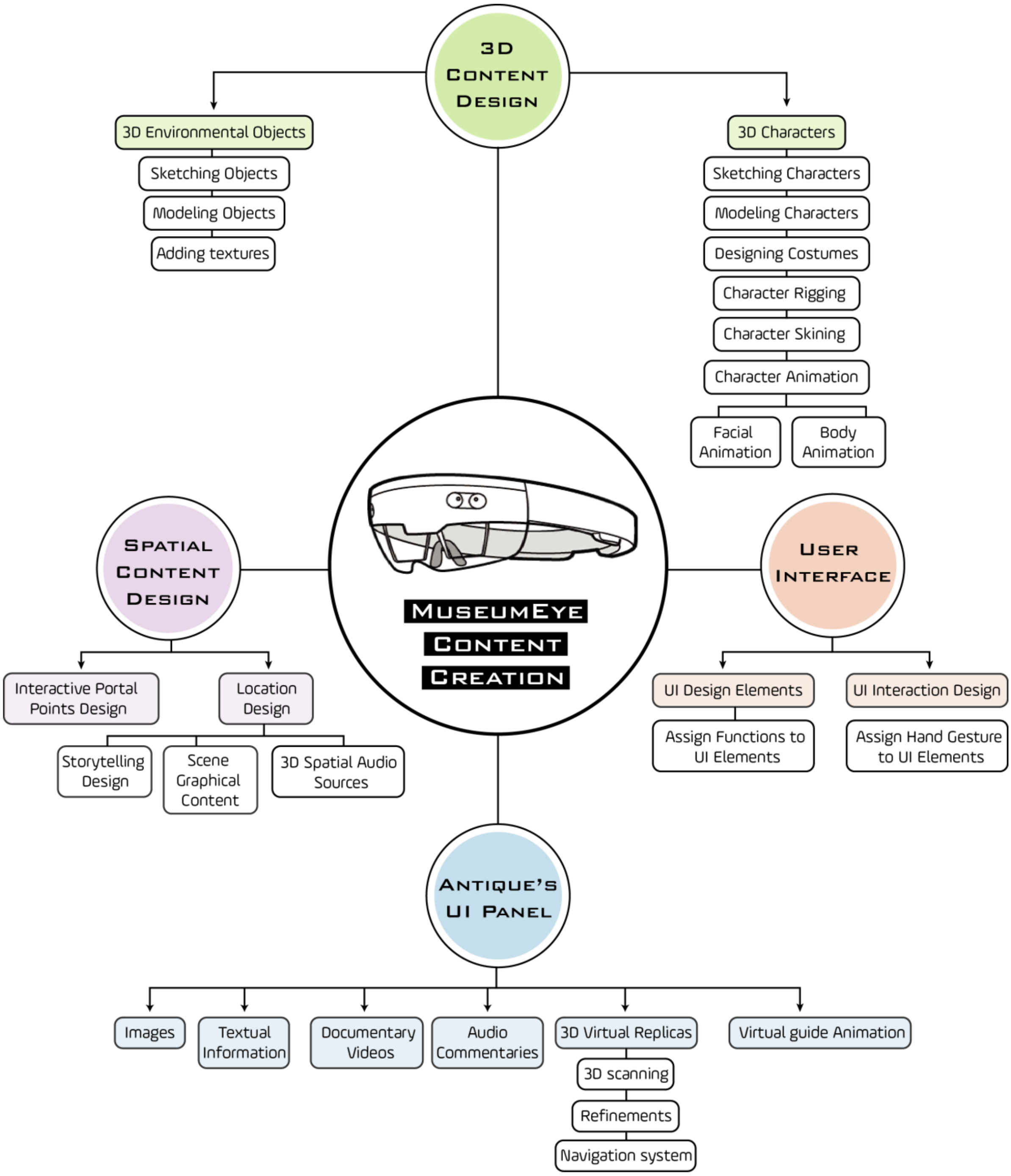

Figure 5.5 MuseumEye Headset Content Design

1. <u>Sketching</u>

The researcher was inspired by the topology of Tutankhamun, based on the digital images taken from the CT scans of the mummy, conducted by Zahi Hawas (Handwerk, 2005). These images helped a team of archaeologists to reconstruct Tutankhamun's face and his bone structure. They provide the researcher with the outline of the main topology of his skull. Then, the avatar of the king was created based on general information from the physical anthropology of Egyptians at that period of time.

2. Modelling

3D tools are utilised to create the 3D model depicted in Figure 5.6, via Autodesk Maya and zBrush. After modelling the avatar, the model was exposed to social media for people living in the same origin city of this Pharaoh. Followed by reviews from special physical anthropologists, their comments were considered and changes were applied.

Figure 5.6 3D Avatar of the King Tutankhamun

Other characters are considered, such as Tutankhamun's wife Ankhesenamun (Figure 5.7) and a couple of guards and maids, as part of the environment, as depicted in Figure 5.8. However, Tutankhamun is considered the main character of the system, since he is the narrator and the virtual tour guide. As a consequence, the researcher put more work into Tutankhamun’s avatar and his representation. Small details have been considered especially in his makeup, such as the length of the eyeliner and the differences between the eyeliner of the king and other people of this period.

Figure 5.7 3D Avatar of the Tutankhamun's wife Ankhesenamun

Figure 5.8 3D visualization of Egyptian avatars representing the king's maids and guards

3. Designing Costumes

3D software such as Marvellous Designer 5 was adopted in this phase as it specialises in designing 3D costumes for 3D characters. Colours, textures, and accessories have been considered carefully for each character. From a technical perspective, it was not easy to build a high-poly model for clothing, due to it being animated and rendered in real-time. High-poly means the 3D mesh of the model is complicated and consists of too many polygons. HoloLens run holograms in real-time, so the models that need to be built should be low-poly, due to the device's limited specifications. It is worth noting that high-poly models can cause lags in the application's performance, or it may even crash the application.

The work begins with creating costumes using Marvellous Designer, and then the models are transferred to Autodesk Maya, in order to cover their bodies with clothes, crowns and accessories, such as earrings, foot slippers, shields, along with arm and hand bracelets. Historical references have been taken into consideration during the costumes design phase, such as books, temples and pictures of tomb inscriptions. Afterwards, the character designs were showcased to several Egyptologists and experts in archaeology for their in-depth critical review, and their feedback was subsequently considered.

4. <u>Character Rigging</u>

The rigging process is to add skeleton to the model for animation. The museum characters went through two different rigging processes: body rigging and facial rigging. As shown in Figure 5.9, the body rig was formed based on the bones hierarchy of the motion capture system we used. Similarly, the facial expressions were not created to deliver rich and subtle expressions to the visitor and to make them more human-look. Also, the facial rigging structure were built to be retargeted to the rigging structure of the facial motion capture system.

The skinning process ensures skin and clothes perfectly attached to the bones, and achieving high fidelity of clothing simulation and smooth movement.

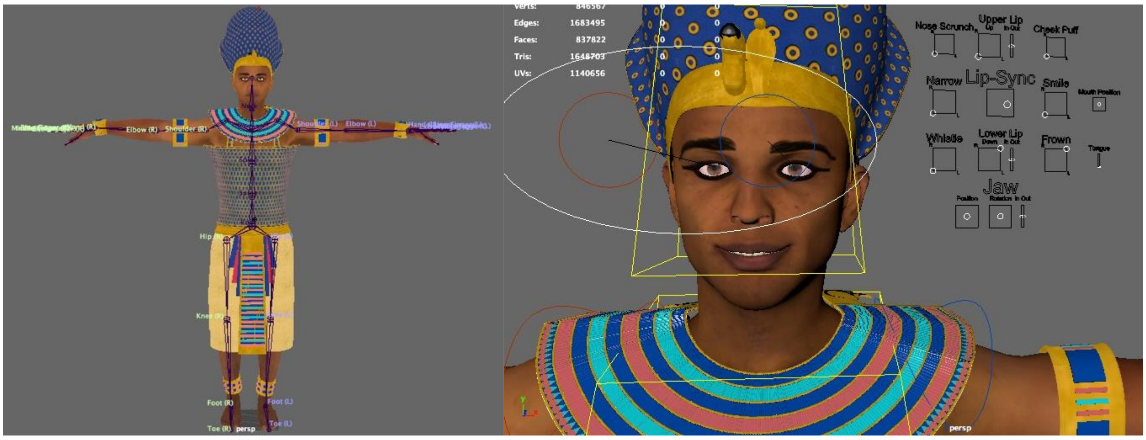

Figure 5.9 Character Rigging process – Left: Body rigging – Right: facial rigging

5. <u>Character Skinning</u>

Following the character pipeline production, the skinning phase comes after making sure the skin and the covered clothes are entirely attached to the created bones. The skinning process also ensures the fidelity of the bones' movements and the smoothness of any further animations.

6. <u>Character Animation</u>

a. Body animation: The ‘Perception Neuron’ motion capture (MoCap) suit was utilised to convert human movement into animation values, which are capable of simulating the animation and adding it to the premade computer graphic characters (Neuron, 2015b). The Neuron MoCap suit is assembled with small wireless magnetic sensors with a three-axis gyroscope that can transfer the movement's values to the Computer Graphics (CG) characters (Neuron, 2015a). Neuron MoCap was utilised previously in a VR museum project for simulating and transferring information to CG characters (SusyNeuron, 2018). The actor as, depicted in Figure 5.10 takes the T-pose as a starting gesture for the body animation then the acting process begins in order to record the narration scenes.

Figure 5.10 Body and facial Motion capture systems
– Left: Body Neuron Mocap – Right: Faceshift Mocap system

b. Facial animation: The ‘Faceshift’ real-time markerless facial capture system was exploited to visually track the human expressions and transfer them to the CG characters (Kokkinara and McDonnell, 2015). The system was used by employing the Kinect camera XBOX 360 for capturing the human facial performance. The Kinect camera, as a sensor contains a colour camera and a depth sensor, which make it capable of facial recognition and translating body language (Zhang, 2012). Kinect was chosen instead of a webcam due to its accuracy and the rich data it can acquire. So, the process starts by acting out the human facial performances in front of the Kinect camera,during which the Faceshift studio can capture the real-time data as depicted in

Figure 5.10. Faceshift studio applies the animation transferred into a default avatar, as shown in the right side of Figure 5.10. Then, it creates a hybrid avatar that combines the actor's facial characteristics and the Faceshift avatar, which is shown in the middle of the aforementioned figure. This generated avatar is mapped to the facial rigging of the virtual guide – the king – in order to eventually transfer and apply the animation to his facial expressions.

The aforementioned two phases were combined together in separated clips for each character and then they were imported to the storytelling scenes, as shown in Figure 5.11.

Figure 5.11 Storytelling scenes after the animations were produced

5.6.1.2 3D Environmental Objects

Following what was discussed in the system mapping design earlier, the current objective is to add a sense of mixed scenes. These scenes are blended into the existing museum hall and the virtual world, as shown in Figure 5.3. It was, therefore, crucial and important to equip the scene with environmental objects. These objects contribute to the scenes by giving the visitor a sense of being in the time and place that the ancient Egyptians used to live in. The creation of these objects went through three phases in order to allocate it within the scene.

1. <u>Sketching Objects</u>

This phase involved both the exploration and investigation of the visual references of the temples, props and interior items from ancient Egyptian history. The sketching objects involved adding ancient inscriptions to the walls and columns of the temple.

2. <u>Modelling Objects</u>

   This phase involved turning the sketches into 3D models and maintaining the simplicity of the shapes in order to make the topology of the models as low poly as possible. This previously mentioned rule is a constraint with all 3D models that are designed to be rendered with the HoloLens hardware. All models were created using Autodesk Maya. The dimensions of the museum hall were taken into consideration while building the virtual temple, with a view to collating both worlds together, as discussed in the system mapping design.

3. <u>Adding Textures</u>

   The inscriptions on the temples were added to the models by using Marvellous Designer. Then, the ground of the virtual temple was discarded due to the confusion that might occur because the physical ground of the museum hall is visible instead.

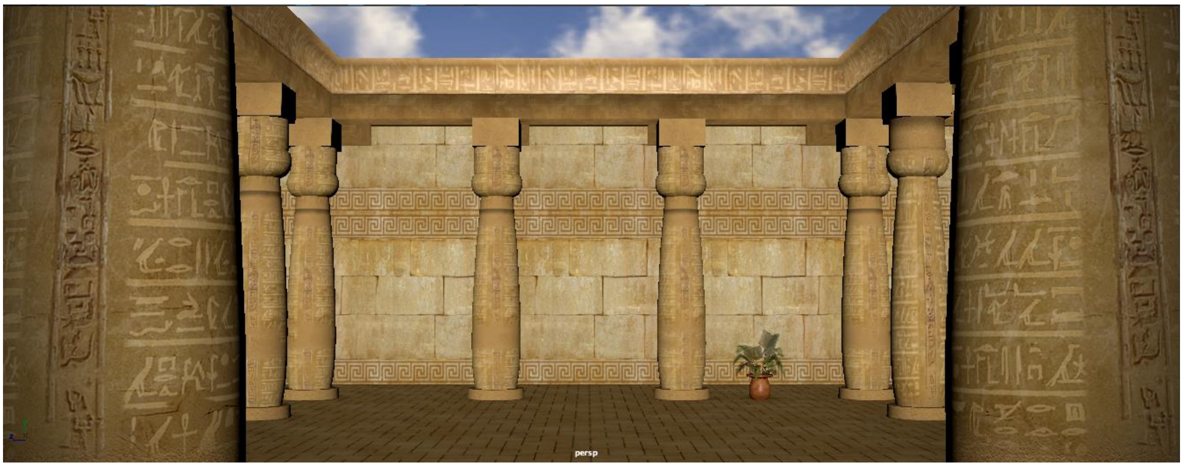

Figure 5.12 After adding textures to the temple model

5.6.2 User Interface (UI)

Designing the system's user interface requires the creation of UI design elements and UI interaction design. There are two essential aspects in order to design the user interface for spatial design: the concept of User Experience (UX) in spatial designs and the usability of the hardware itself.

Regarding the first aspect, surprisingly, there is a lack of existing knowledge regarding the UX of the spatial design system, particularly for optical-see-through HMDs and their interactions. Concerning the second aspect of the hardware, Microsoft HoloLens, the field of view (FOV) is quite narrow, since according to Bimber and Bruns (2011) it is 34°. However, Keighrey et al. (2017) stated that the lens has a FOV of 30° by 17.5°. Furthermore, the limitation of the FOV of HoloLens presents challenges in developing the UI and UX for the 'hBIM' project, which leads to a rapid disappearance of the content from the user frustum view (Fonnet et al., 2017). Also in 'Holo3DGIS', the authors stated that their system cannot display the content in the user's visual space (Wang et al., 2018b). These unexplored UX concepts motivated the researcher to investigate and practice designing the spatial design by finding a workaround in order to enhance usability and the user's experience.

Therefore, it was a challenge to design an interface and guarantee usability, despite whether the user is capable of interaction or not. The hand gestures assigned to Microsoft HoloLens were very few, so it was important to utilise them for most of the interactions needed. The researcher wondered if the users could make the hand gestures with the floating UI and if they could click/air tap as expected, even with minimal instructions. Therefore, the instructions about interacting with the text and images were presented to the user before the interactions or initiating the functions was needed.

The first idea to design the spatial UI is to design it as a half curve, with all the visuals surrounding the user. This approach was adopted in order to make all the interactive points more reachable to the user and to ease any interactions. As depicted in Figure 5.13, the brightened area is what the user can actually see from the whole scene, and the semi-blacked area represents the unseen parts of the scene. In reality, the blacked area represents the actual environment without virtual content, but the aforementioned figure manifests the problem of missing content due to the narrow FOV.

Unsurprisingly, and due to the limited FOV, what was seen from the HoloLens viewport resulted in clipped scenes, as depicted in Figure 5.14. Because of this incoherent UI scene, users cannot notice the existence of the missing content, whether it is in the left or the right side of the user. Therefore, a series of experimental methods were conducted based on Bowman and Hodges (1999) and outside factors (Blokša, 2017), which were part of their study (Hammady and Ma, 2019). By considering all these factors that were integrated with the testing interventions, a significant learning curve was noticed. Figure 5.16 depicts, the UX principles required for HoloLens UI design.

1- <u>Task characteristics</u>: as described by Bowman and Hodges (1999), the task characteristics represent all aspects that influence performance. In the UI prototype, the user undertakes several activities that affect the way of performing towards it. The user must walk to the UI, aim with his/her head, centre their gaze point, then perform air-taps. This is in addition to looking around and watching people walking while observing the authentic exhibited

Figure 5.13 Spatial UI Design as seen from HoloLens

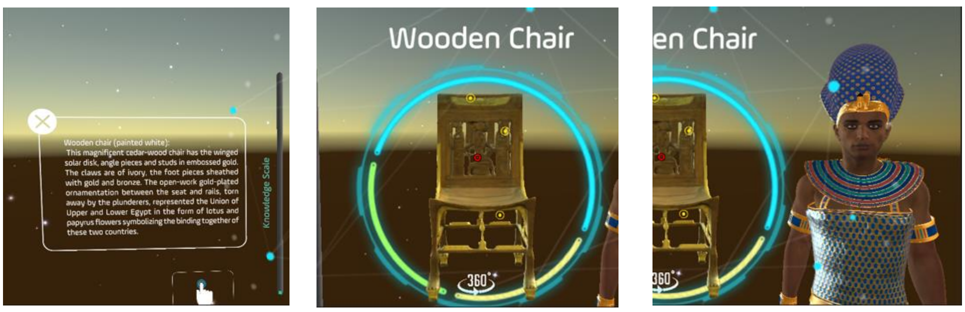

Figure 5.14 Cropped scene as the HoloLens user can see

item. The interactions with the virtual replica require a dragged hand-gesture to rotate the object. This set of activities requires specific attributes to be taken care of:

a. *Distance to be travelled*: Due to the limited FOV, what the user can see is merely a quarter of the scene. Moreover, the user has to see the exhibited antique with the UI together. Also, it was calculated that the best distance from the UI is one meter in order to enable proper hand interaction with the UI. However, in order to see the entire desired scene, the user has to move back 2.2 meters to view it as depicted in Figure 5.15. The challenge was in the scene triggers that are supposed to be activated close to the exhibited antique. At the first attempt, the scene triggers were allocated one meter away from the exhibited item. Unsurprisingly, users could not recognise the entire scene in this attempt, however, voice commands or instructions were added to look left and right. The second attempt went better than before, as the scene triggers were allocated to a distance of 2.2 meters away from the exhibited item. The UI was distant, and the location of the triggers was not in the desired location, however, the users could see the whole scene. With minor voice and visual instructions, users came closer to interact with the UI and could realise the existence of the whole scene.

b. *Size of the object being manipulated:* Based on the resulting measurements of the test of the participants, the best distance to perform the interaction is one meter. Moreover, the most appropriate size that the participants felt convenient was over 50cm in height and 50cm in width. It is worth mentioning that most of the participants were exposed to minimal instructions in terms of how to perform the air-tap and make the dragging gesture.

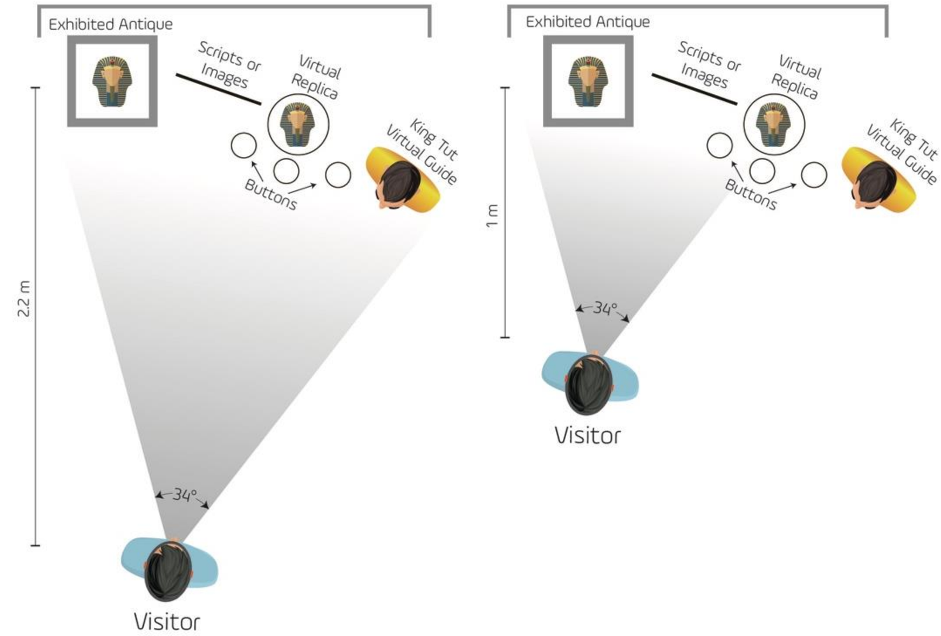

Figure 5.15 Visualising the entire seen from different locations

2- Environmental characteristics: Interacting with HoloLens requires adequate space. Therefore, the characteristics of the space were taken into consideration by involving some variables in the interactions process.

a. *Number of obstacles:* While running the application, it was concluded that the user requires an empty area in front of him/her to place the visuals. If people pass in front of the user, this might change the location of the UI, due to the intrusion deforming the spatial mapping of the actual location. This problem is common in museums, since they are expected to have many visitors occupying the same spot.

b. *Lighting levels:* It is preferable to display visuals in low-level lighting conditions and the visual opacity increases with interior lighting conditions. Sunlight decreases the opacity percentages, and the visuals start to lose their opaqueness.

3- User characteristics: All aspects relating to the user himself/herself regarding both the physical and cognitive attributes.

a. *Cognitive measures:* The participant group were instructed minimally in terms of the way they interact and perform the air-tap. During the experimental phases, different levels of acquiring the interaction skills were noticed, which reflects an uneven retention of the instructions. Getting accustomed to the HoloLens interactions takes more time with some people and no time with others.

b. *Physical aspects:* The diversity of the participants' heights was noticed during testing interventions. The visuals ware designed to be appropriate for a person of 1.70 meters in height. However, it was noticed that shorter participants tended to look up to the visuals, which was cumbersome for them and caused pain in their necks after time. There was a similar problem for participants who were taller than 1.70 metres. After several attempts, the researcher was driven to scale the whole UI based on the person's height. Once the scene opens, it calculates the distance between the ground and the camera of the HoloLens. Then, it scales the whole UI based on it. This level of customisation made the experience more convenient for the participants.

4- <u>System characteristics:</u> These are all aspects that were relevant to the headset, the application, or the hardware specifications.

a. *Frame rate of the scene:* Rapid streaming of the physical visualisation was noticed, which combined with the virtual content when the complexity of 3D graphics was minor. On the contrary, if the current frame that the user is

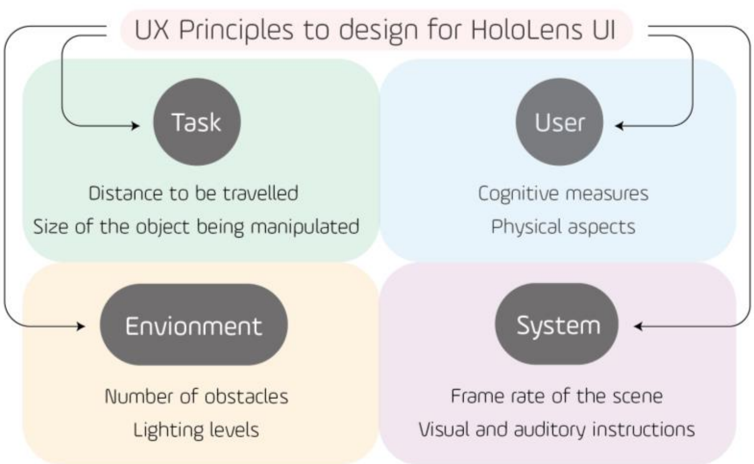

Figure 5.16 UX principles for HoloLens UI Design developed from (Bowman and Hodges, 1999).

observing from the HoloLens viewport involves many complex 3D models, the frame rate will drop to 15 – 20 frames per second. This also could cause lags and delay in rendering the current frame. So, from a spatial design perspective, distributing complex 3D visuals around the space with adequate room in order to avoid seeing them together in one frame is recommended.

b. *Visual and auditory instructions:* Based on the UX concepts, the user should be aware of all visuals that are designed to be seen or heard. Therefore, the ‘tag along method’ was used, which gives the user a visual clue that points to the location of the virtual content in the space around the object. This method was adopted by Fonnet et al. (2017), as it ensures that the content is continuously only a glance away from the users. Additionally, auditory instructions were utilised to compensate for the visual instructions if there was no room for the former method.

5.6.3 Spatial Content Design

5.6.3.1 Interactive Portal Points Design

Interactive portal points were designed in order to be placed in front of the exhibited items as depicted in Figure 5.17. Once the visitor arrives at this point, it is triggered and takes the visitor to a new scene. Other portal points are placed in particular spots in order to initiate a storytelling scene with a set of characters which represent the ancient Egyptian people.

Figure 5.17 Interactive points are allocated at the museum hall.

5.6.3.2 Location Design

a. 3D Spatial Audio Sources: Location design involves adding ambient audio sources since the HoloLens has the capability to allocate 3D spatial audio sources and the visitor can physically feel the location of the audio source. Furthermore, the animations of the characters were designed and reoriented within physical location boundaries in order to avoid bottlenecks in the path or crowded spots in the targeted room. There are some scenes in particular, which involve historical battles – as depicted in Figure 5.18 – that require much more space in the room.

b. Scene Graphical Content: This phase involves adding all characters, props (such as golden thrones and decoration objects) and UI elements. These graphical items were allocated based on the plans discussed earlier in the system mapping designs.

c. Storytelling Design: Storytelling was designed to support the viewer with as many visual sources as possible, for instance, when the virtual narrator mentions one of the figures of the story, a floating image appears to support the story and add another layer to the museum experience.

   Storytelling also helps visitors with a visual memory when they are exposed to this information. The script was created to be simple, straightforward, interesting with different animations and without a great amount of complicated information. It was created to suit a wide segment of the visitors, who were not specialised in Egyptian history. However, there was more

Figure 5.18 Shots from what visitor can see from HMD inside the Egyptian museum in Cairo

information provided if the visitor was interested, by interacting with the UI buttons in the scene. The aim of designing these storytelling scenes is to allocate the user and immerse him/her in the middle of the action, including the time. This approach attempts to make the visitor not only an observer of what the history left for him/her, but it also makes him/her a witness to the events as he/she travels through time to listen to the story from the King himself.

5.6.4 Antique's UI Panel

Once the visitor decides to stand at the interactive point in front of the selected exhibited item, he/she expects to be provided with all supplementary information relevant to the exhibit. It is important to satisfy different interests by unlocking various levels of information via different methods, such as images, text, and audio narrations. So, the content is prepared with all visual and acoustic information, along with the ability to discover the antique with a sense of controlling the antique through the user's interactions. In order to accomplish the latter function, the antique replicas were scanned by a 3D scanner named 'Cubify Sense 3D' to acquire the 3D virtual replica. Some of the virtual antiques of the targeted collection were provided courtesy of Bibliotheca Alexandrina (CULTNAT). Then, a set of refinements were made to ensure that the model was more identical to the original piece. A navigation system was designed and triggered by hand gestures to allow the user to spin the antique 360° around itself. This function enables the visitor to view the exhibited item from all angles, due to the limited ways of displaying the antiques in the museum.

Small tips in the text appear once the user taps on them, which contain interesting information about each part of the piece. Moreover, there are some animated/flashing icons that motivate the user to keep discovering the item, and these connect with a progress bar named 'knowledge scale'. This scale keeps moving as long as the visitor reveals the secret information in these small tips around the item. Once the visitor reveals all the secret tips, an award sound effect will play indicating the exploration game has finished. Regarding the textual information, the system presents large and obvious labels to visitors, which are better than the small physical labels in the display. Also, they represent the narrations performed by the king, so if someone did not follow what the virtual guide said, he/she could read these floating windows – as depicted in Figure 5.19. There are a number of buttons that float around the antique's UI, such as images that can help the visitor see additional images while hearing the narration. Moreover, the replay narration button can help the visitor if he/she would like to play again at any point. Some buttons can give the visitor the freedom to leave the current scene or enter another one. These buttons were designed and allocated to make it easy for the user in all the antique scenes.

The information provided by the navigation scenes was chosen to be interesting in order to motivate the user to go deeper into discovering the antique and continue exploring and learn the secrets of the relics, the reasons behind building it, along with the inscriptions engraved on the different angles of the antique. This approach can change the visitor's behaviour from being just an observer to an explorer.

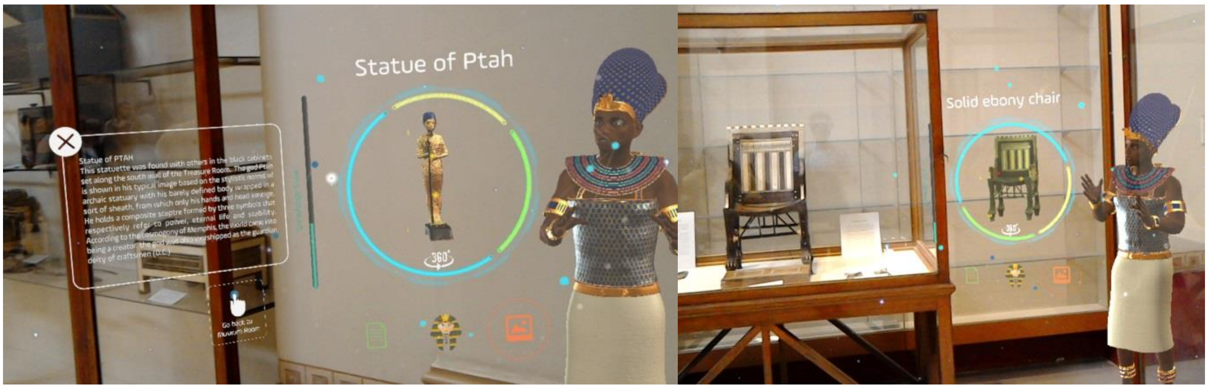

Figure 5.19 Antique's UI panel with the virtual guide – avatar of King Tutankhamun

As part of this study's outcomes, the system provided five lines of interaction, as depicted in Figure 5.20. Firstly, the visitor in front of the exhibited item will interact with the physical environment, including co-visitors, ambient music and environmental sound. Secondly, the vistor will interact with the original exhibited item. Thirdly, the visitor will interact with the virtual guide and watch his performances and facial expressions. Fourthly, the visitor will interact with the virtual replica by spinning it and reading the information around it. Fifthly, the visitor can interact with the user interface, including the buttons. The more interactions the visitors have with the interface, the more interesting and the better their retention of the information will be.

This interactive environment can raise the level of concentration and knowledge consumption of the user. This context can also motivate his/her cognitive ability, which eventually reflects on the impact that this experience can leave on the visitor by the end of the tour.

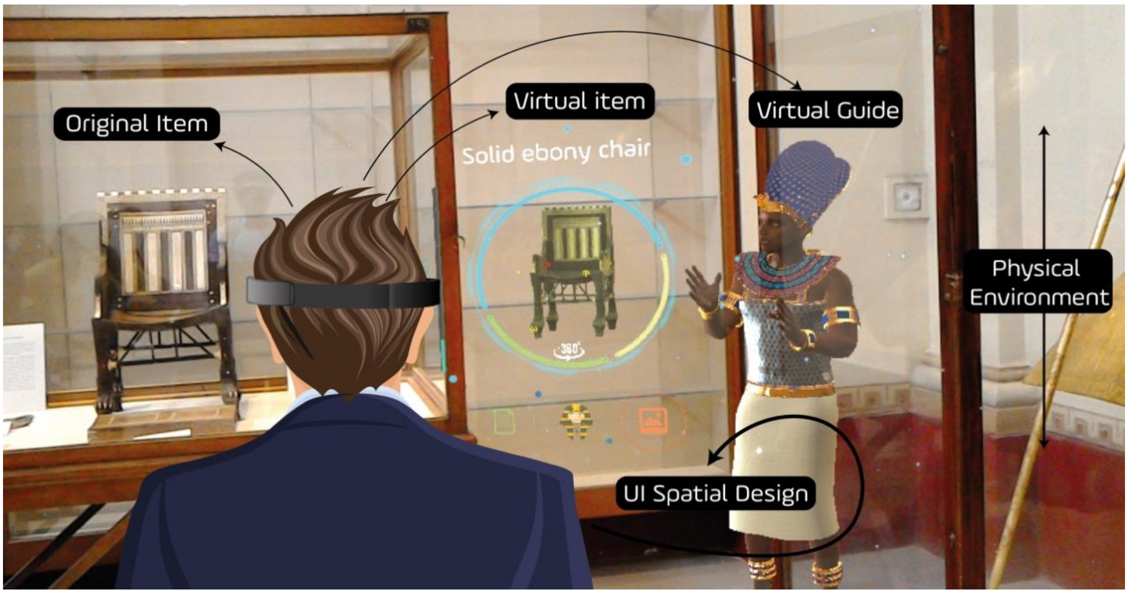

Figure 5.20 MuseumEye interaction lines

5.7 Stage 4: MuseumEye Development Process

5.7.1 System Architecture Pipeline

The storyboard of the system was the source of creating the system content, which also manifests in the method of building it and where it will be in the system. As depicted in Figure 5.21, the pipeline starts from the storyboard, which involves different types of software, based on the nature of the content. All the content is fed to the game engine 'Unity3D', which is responsible for creating the scenes, developing the interactions, integrating the content, and exporting the application to the HoloLens. Once the application is deployed, the testing phase starts, which can take a considerable amount of time before it can apply in the museum. It is important to make sure the system does not suffer from any lags, errors or bugs in order to ensure sustainability during the visit. Thus, the loop of amendments was continuous until the testing phase proved the validity of the system.

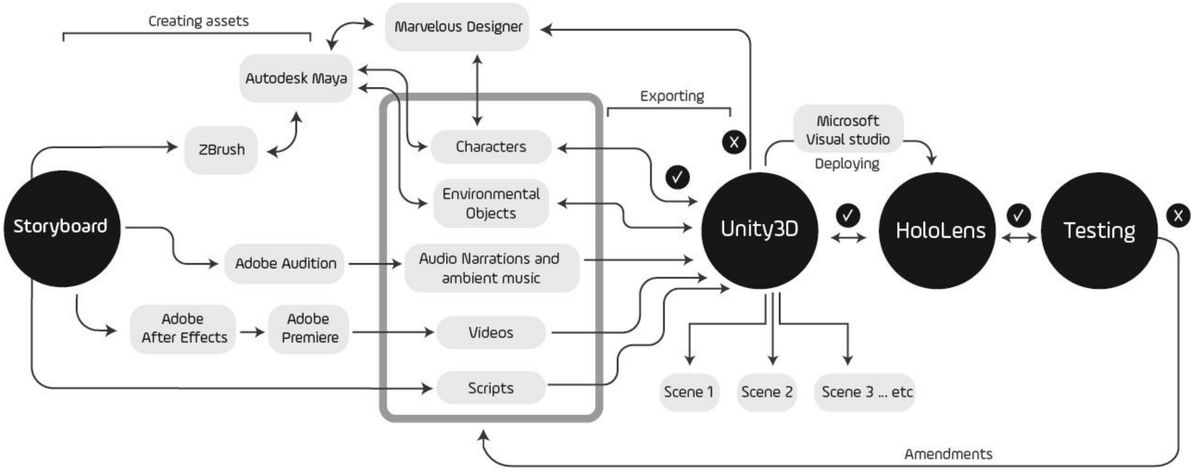

Figure 5.21 Development pipeline of MuseumEye

A group of volunteered participants were involved during the testing phase. They received a short tutorial for using the system and the hardware, including the interactive hand gesture required before testing; they then provided their feedback.

5.7.2 System Walkthrough of MuseumEye

The system scenario was designed flexibly according to what the visitor desired during his/her tour. This means that the visitor has full authority and controls jumping from one scene to another. This concept contradicts the prepared thematic tour that is performed by human or audio guides. When the visitor feels that he/she is the controller of their visit, this increases the possibility of enjoying and learning from the tour.

As depicted in Figure 5.22, the intro scene starts, then it takes the visitor to ‘Station 1’, where the king introduces himself to the visitor, explaining everything in the context of the room. Once ‘Station 1’ ends, the user can see the portal points allocated to the ground next to the antique, which they can then explore. So, the user can choose to either go to the navigation scenes of these exhibited items or continue the theme of storytelling scenes by stepping on these scene portals. The user has full control over identifying where he/she is in the system, so leaving the current scene and jumping to another is possible. It is important to make the user feel that he/she has the full authority of interaction and change the ambient environment more than allocating him/her in an automated lengthy prepared scenario where they have minimal control. Moreover, it is important to emphasise on the scene of independence that the user is looking for and obtain information where and when the user requires.

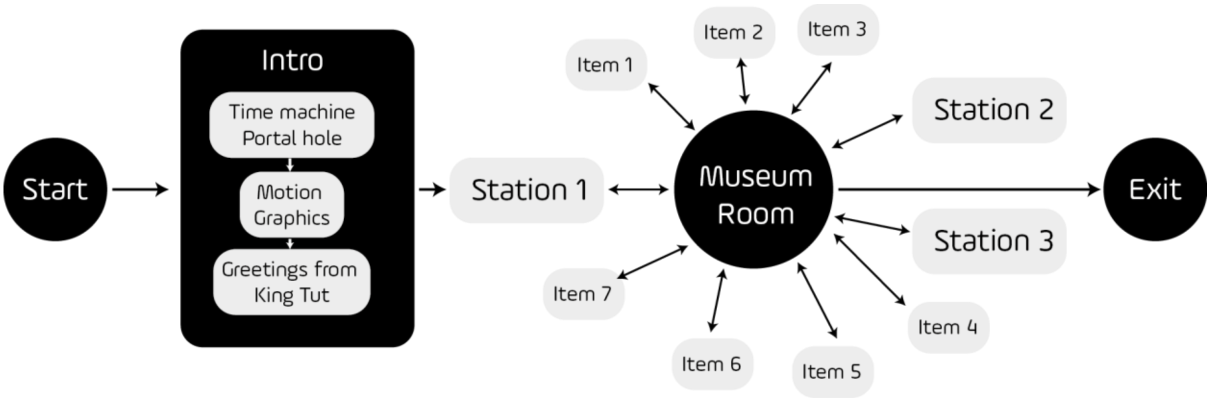

Figure 5.22 MuseumEye walkthrough

5.8 Deployment and Installation

Due to building the system away from the museum location, one phase remained until the researcher arrived at the targeted museum hall. This phase involved scanning the location spatially and loading it with the virtual environment. Therefore, the developer has the ability to control the location of the scene portals – which are depicted in Figure 5.17 – and place them next to the relevant exhibited item. Once it is allocated to this point, it can last forever, and the user has no control over changing its place since it is anchored to the real world, using the current world's visual cues. Also, the locations of the storytelling scenes were allocated according to the system mapping design in Figure 5.2.

Furthermore, testing occurred on location to make sure the virtual surface of the virtual characters, props and the temple were aligned with the physical surface since this might confuse the museum visitors. This phase also involved checking the lighting levels of the museum hall to investigate whether it is suitable for the opacity of the holograms and to further ensure the sunlight does not penetrate the space of the presented visuals. Finally, a few tests were applied to ensure the stability of the system during the experiment; this phase is defined as quality assurance, and it is crucial for the system's sustainability.

5.9 Summary

This chapter has showcased the MuseumEye system design and development, which consisted of four stages. The first stage involved the inputs, which include the relevant literature review and the outcomes of the observation study, then the second stage consisted of the system structure design. This was followed by the third phase, which involved the system content design, and finally, the MuseumEye development process. This chapter has presented the way the system was constructed as a prototype from the initial stage through to preparing it for its use in the targeted location, which is the Egyptian Museum in Cairo – King Tutankhamun's room.

Chapter 6:
MuseumEye Data Analysis and Discussions

6.1 Introduction

This chapter presents the data results after demonstrating the evaluation methodology in chapter 4. It starts by demonstrating the quantitative and qualitative results after conducting an analysis of the integration of visual representations. Both evaluation methods (surveys and observation) were employed to explore and answer the study's research questions. The quantitative method in this study assessed the theoretical framework that was proposed in chapter 4. Considering the nature of the field study conducted and its correspondence with the human being, unforeseen findings were expected, which could have implications on the entire research's findings. This chapter ends with a critical comparison between the human guide and the designed MR virtual guide in terms of the traditional roles of the museum guide.

6.2 Survey - Questionnaires

6.2.1 Participants/Visitors' profiles

The visitors who participated in the experiment were adults aged between 18-60. The sample size approached 200, however, 29 participants did not complete their questionnaires, which were subsequently discarded, as depicted in Table 6.1. The valid sample size was 171, with fairly equal representation in terms of gender: 57.3% male and 42.7% female. The participants were divided into three age groups, as depicted in Figure 6.1. The age groups from 18 to 25 and 24-40 were represented the sample with percentages 47.4% and 42.1%, respectively. These results represent a high level of interest for experiencing new technologies in museums from the younger groups in contrast with the older participants since the latter group resulted in 10.5% of the sample size.

Table 6.1 Demographic information

		Age	Gender
N	Valid	171	171
	Not valid	29	29
Mean		1.63	1.57
Median		2.00	2.00
Std. Deviation		.668	.496

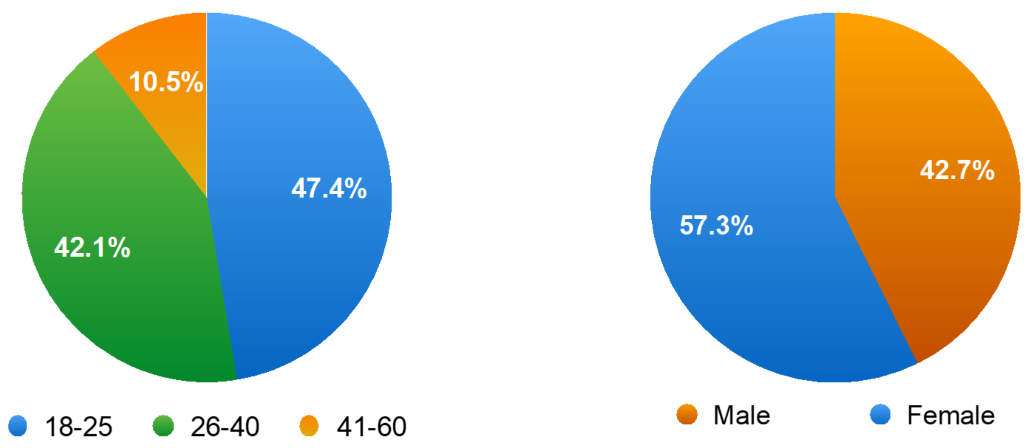

Figure 6.1 Demographic groups charts - age group on the left and gender group on the right

6.2.2. Participants Awareness of AR

The participants were asked questions about their prior knowledge of AR or VR technologies and whether they had experienced AR before. As shown in Figure 6.2, 120 participants (70.2%) were aware of AR or VR technology. Moreover, 73 participants (42.7%) had heard of AR apps, such as Layar, Wikitude or Pokémon Go. 56 participants (32.7%) had experience with wearing AR/VR headsets/smart glasses. This was followed by an open question asking the participant to confirm what device they had worn before. Interestingly, these participants had experience with Oculus Rift, HTC Vive, Samsung VR Gear, Google Cardboard, VR Box or Microsoft HoloLens. Then, 44 (25.7%) participants had experienced AR applications before and 9 (5.3%) had experienced AR in museums. All of the 9 participants had experienced AR in "The Wall of Knowledge" (Cultnat, 2016) exhibition at the same museum.

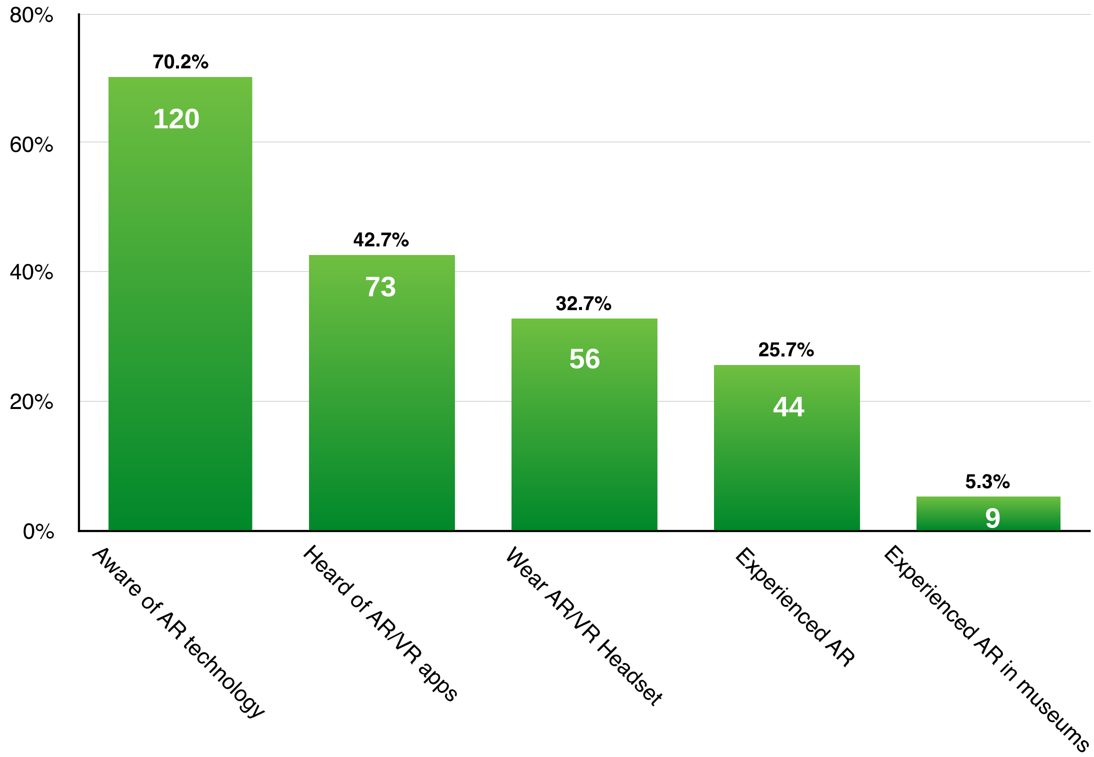

Figure 6.2 Frequencies and percentages of AR awareness

6.2.2.1 Awareness of AR by age group

The responses of the age groups on AR awareness are represented in Figure 6.3. Unsurprisingly, age group 41-60 has less knowledge of and experience with AR/VR than the younger groups of 18-25 and 26–40. Meanwhile, the age group 18-25 was much higher than the age group 26-40 in some aspects, such as in terms of awareness of AR percentages, which were 76.5% and 69.4%, respectively. Similarly, the question in relation to the visitors' awareness of AR apps shows higher responses in the age group 18-25, at 49.4%, which is greater than the age group 26-40, at 36.1%. The question that explores whether the participant has worn an AR/VR headset before shows similar responses of 33.4% and 36.1% respectively. Similarly, the question regarding prior experience with AR got 25.9% and 29.2% respectively. However, the question of experiencing AR in museums was opposite to the previous results, as the age group 18-25 was less experienced (1.2%) than the age group 26-40 (9.7%).

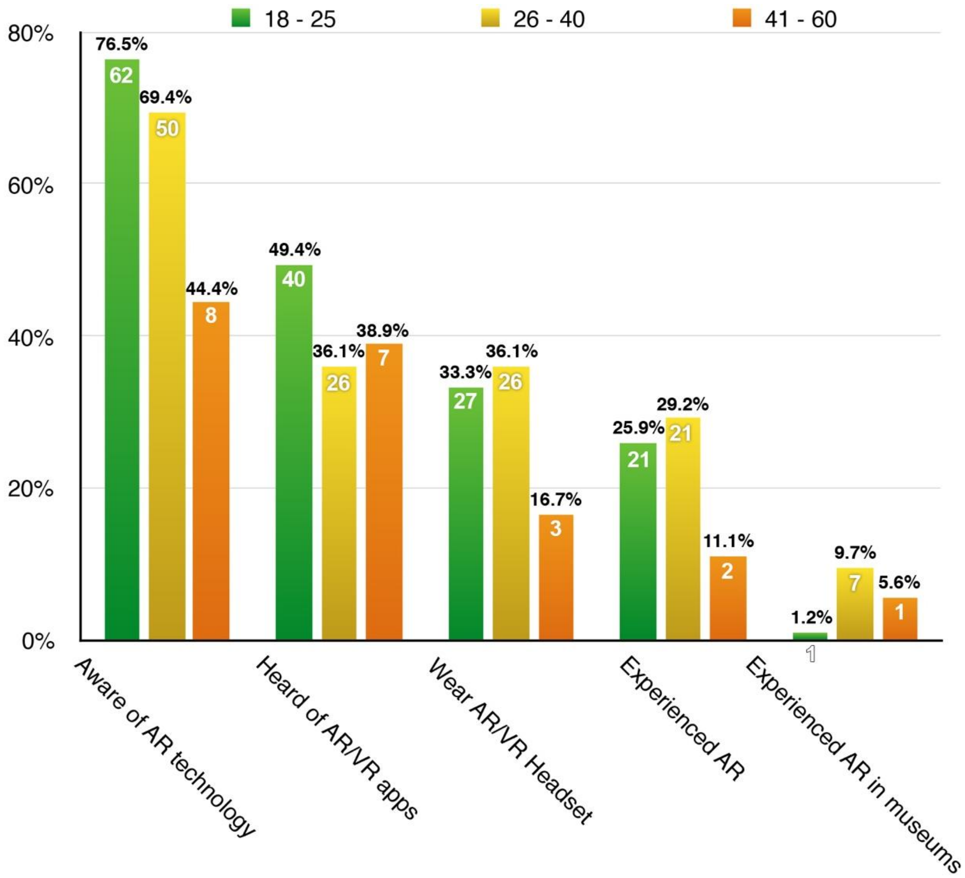

Figure 6.3 Awareness of AR graph for age groups

6.2.2.2 Awareness of AR by gender group

This section explores the responses of the gender groups towards the AR awareness or experience as shown in Figure 6.4. Apparently, all responses from males towards the AR/VR awareness and experience questions were higher than for females. For instance, the awareness of AR technology resulted in 72.6% for males and 68.4% for females. Then, the question of having heard of AR/VR apps, males responded with 47.9% and females reacted with 38.8%. For the question regarding wearing AR/VR Headsets, males responded with 39.7% and females with 27.6%. Then, the experience of AR question was resulted in 28.8% responses for males and 23.5% for females. Finally, the question relevant to experiencing AR in museums resulted in 8.2% for males and 3.2% for females.

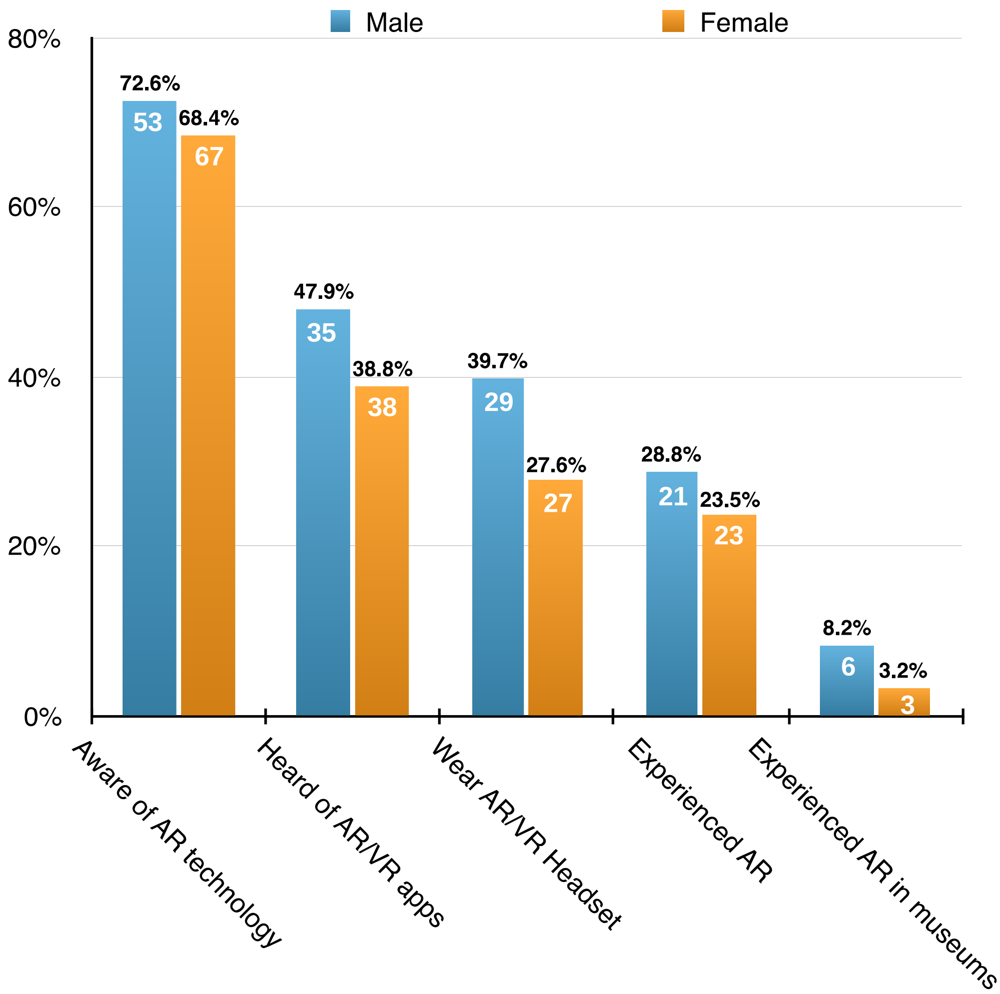

Figure 6.4 Awareness of AR graph for gender groups

6.2.3 Participants' Survey Analysis

The survey analysis consists of two phases. Firstly, a descriptive analysis, and secondly, testing the hypothesis of the proposed framework.

6.2.3.1 Descriptive Analysis

There were 27 system evaluation questions, which were formed and distributed to be adequate and sufficient for each construct, which in turn ranged between 3 to 5 questions per construct.

Table 6.2 Composition of all evaluation constructs for participants

Constructs in Technology Acceptance Model	No. of questions	Minimum	Maximum	Mean	Std. Deviation
Enjoyment (ENJ)	5	2.20	5.00	4.37	.52
Usefulness (USF)	4	3.00	5.00	4.37	.51
Multimedia and UI (MUI)	4	1.00	5.00	4.33	.62
Ease of Use (EOU)	4	3.00	5.00	4.39	.50
Interactivity (INT)	3	1.00	5.00	4.13	.74
Role of being a guide (ROG)	4	2.00	5.00	4.38	.61
Intention to Use (ITU)	3	2.50	5.00	4.55	.57

Table 6.1 depicts the minimum, maximum, standard deviation, and the overall mean values of the seven aspects. The lowest minimum value of the aspects was the 'Interactivity' as 1.00 and the highest is 3.00 for two aspects, 'Usefulness' and 'Ease of Use'. Interestingly, all maximum values are 5.00. Regarding the mean values, the highest mean value is 4.55 for the ''Intention to use'' aspect and the lowest mean values is 4.13 for the 'Interactivity'. Moreover, two mean values are identical as they are 4.33. Also, another two values are almost identical as they are 4.38 and 4.39 for the aspects 'Ease of use' and 'Role of being a guide' respectively. Generally, most of the mean values represent strong positive responses towards using the system in the targeted museum.

6.2.3.2 Correlation, Regression Analysis, and Hypothesis Tests

This section analyses the relations between the constructs, and further tests the hypotheses of the proposed framework presented in Figure 4.3.

Table 6.3 presents the seven constructs with their explored items, then presents the Exploratory Factor Analysis (EFA), the Confirmatory Factor Analysis (CFA), the Average Variance Extracted (AVE), and the Cronbach' alpha (α).

A. Exploratory Factor Analysis (EFA)

All the factors and the questions were adopted from previous studies and are theory driven, except for the variable 'Role of the Guide', which emerged from the system development stage. Therefore, the EFA was conducted to explore the structure of the relationship between the other variables and the emerged variable (Costello and Osborne, 2005). EFA is usually adopted to *"identify the factor structure or model for a set of variables"* (Bandalos, 1996). Researchers adopt EFA to search for the minor set of latent factors that represent a significant set of variables (Henson and Roberts, 2006). A statistical software package has been used (SPSS) for calculating the EFA results by using a fixed number of factors (7) as an extraction, with Varimax rotation. Also, the results were customised to represent values that were above 0.60.

B. Confirmatory Factor Analysis (CFA)

CFA is usually used for testing theories when the analyst has adequately strong justification regarding what factors should be considered in the data and what variables should represent each factor (Henson and Roberts, 2006). The need for testing CFA after EFA is simply because EFA explores those factors that best regenerate the variables under the maximum likelihood conditions, while CFA explores a particular hypothesis concerning the nature of the factors (Gorsuch, 1983). CFA was conducted by AMOS software in order to assess unidimensionality. All the items were above 0.5 which is the acceptable cut off point (Comrey and Lee, 2013), as shown in Table 6.3.

C. Cronbach's alpha (α)

Table 6.3 also shows a test of internal reliability or Cronbach's *Alpha* (α), which is a tool for assessing the reliability of the scale of multi-point questionnaires

Table 6.3 Construct reliability and convergent validity coefficient

	EFA	CFA	AVE	α
Enjoyment			.50	.83
ENJ1	.77	.77		
ENJ2	.71	.65		
ENJ3	.69	.71		
ENJ4	.69	.70		
ENJ5	.65	.69		
Usefulness			.51	.80
USF1	.67	.72		
USF2	.75	.74		
USF3	.66	.65		
USF4	.69	.73		
Multimedia			.57	.83
MUI1	.77	.78		
MUI2	.75	.72		
MUI3	.71	.72		
MUI4	.80	.78		
Ease of Use			.50	.81
EOU1	.74	.76		
EOU2	.65	.60		
EOU3	.68	.66		
EOU4	.73	.78		
Interactivity			.62	.85
INT1	.80	.75		
INT2	.81	.85		
INT3	.74	.77		
Role of guide			.63	.87
ROG1	.72	.76		
ROG2	.84	.83		
ROG3	.79	.82		
ROG4	.74	.75		
Intention to use			.50	.84
ITU1	.68	.72		
ITU2	.75	.73		
ITU3	.69	.67		

(Santos, 1999, Cronbach and Warrington, 1951). According to Table 6.3, 7 constructs were tested to present the level of reliability through the Cronbach's *alpha*. The values show adequate reliability levels, as indicated by Taber (2017), the adequate reliability values must be between 0.64 and 0.85. The minimum α is 'Usefulness', with a value of 0.80, and the maximum (α) is the 'Role of being a Guide', with a value of 0.87.

D. Average Variance Extracted (AVE)

Table 6.3, represents the instrument validity through average variance extracted (AVE), where the results indicated that all the variables exceed the recommended standard 0.7 and 0.5 for all construct respectively (Hair, 2015).

E. Correlations and Discriminant Validity

The discriminant validity is achieved when the square root of AVE is larger than the square on the correlation (Wang et al., 2012). As a result, Table 6.4 indicates that all measures achieved the discriminate validity standard. In other words, the factors can test what the other variables cannot (Hair et al., 2010). The correlation test is summarised in Table 6.4 with a diagonal value. Considering $p<0.01$, all of these indicators were statistically acceptable (Wooldridge, 2015).

Table 6.4 Correlation and Discriminant validity

	ENJ	USF	MUI	INT	EOU	ROG	ITU	Discriminant validity
ENJ	**.71**							**.71**
USF	.49**	**.71**						**.71**
MUI	.47**	.46**	**.75**					**.75**
INT	.45**	.51**	.48**	**.71**				**.71**
EOU	.32**	.29**	.45**	.36**	**.79**			**.79**
ROG	.46**	.43**	.50**	.53**	.29**	**.79**		**.79**
ITU	.35**	.32**	.42**	.37**	.29**	.66**	**.71**	**.71**

** Correlation is significant at the 0.01 level (2-tailed).

F. Testing Hypothesis

The PROCESS has been used to test the hypotheses. The PROCESS is an analysis tool that was developed by Hayes (2013). PROCESS enables testing the direct and indirect impact, and it allows for testing more than one mediators without sample size restrictions which is a key issue in other tools, such as 'Structure Equation Modelling' (Hayes, 2012, Hayes, 2013). PROCESS results do not differ much from the structure equation model results, however, PROCESS calculates each equation sedately instead of concurrently (Hayes et al., 2017). The path is considered significant when its Confidence Interval (CI) does not contain zero (Hayes, 2013).

The mediation test runs through the bootstrap (5000), which is the recommended number for the bootstrap (Preacher and Hayes, 2008). The bootstrap has been chosen to test the mediation impact as it deals with type I error (reject the true null hypotheses) and can provide correct results despite the sample size (Preacher and Hayes, 2008, Claudy et al., 2016).

Table 6.5 Correlation and Discriminant validity

Indirect Effect			
		Model 1 → ROG → ITU	Model 2 → ENJ → ITU
USF	β	.19**	.03
	R^2	.27	.25
	MSE	.28	.21
INT	β	.27**	
	R^2	.44	
	MSE	.19	
MUI	β	.28**	
	R^2	.45	
	MSE	.19	
EOU	β	.21**	
	R^2	.45	
	MSE	.18	

Direct Effect			
		β	t
H1	USF → ITU	.03	.34
H2	ENJ → ITU	.06	.75
H4	INT → ITU	.02	.29
H8	ROG → ITU	.61*	9.5
H5	MUI → ITU	.35*	4.5
H7	EOU → ITU	.10	1.07
H6	MUI → EOU	.44*	8.56

** CI 95% does not contain zero. *Significant P <.01 MSE=Mean Square Error

The hypotheses were tested using PROCESS, where both direct and indirect relationships were measured, as depicted in Table 6.5 (Hayes, 2017). The indirect effect between the constructs (Usefulness, Interactivity, Multimedia & UI, and Ease of use) and Intention of Use was represented in two models where each model contains one mediator, namely, Role of Guide for model 1 and Enjoyment for model 2. The results demonstrated that the Role of Guide significantly mediates the relationship between Usefulness and the intention to use (ß = .19, CI95%= .08, .33; R^2=.27), which supports H9. Model 2 showed that Enjoyment does not mediate the relationship between Usefulness and intention to use (β = .03, CI95%= .06, .12; R^2=.25), rejecting H3. Model 1 further represented the significant mediation of Role of Guide between Interactivity, Multimedia, Ease of Use from one side and Intention of Use from the other side (β = .27, CI95%= .18, .40; R^2=.44), (β = .28, CI95%= .16, .48; R^2=.45), (β = .21, CI95%= .09, .39; R^2=.45) respectively, supporting H10, H11, and H12.

The direct impact shows that only the Multimedia variable has a significant direct impact on intention to use (β = .35, t=4.5, p<.01), supporting H5. Usefulness (β = .03, t=.34, p>.05), Enjoyment (β = .06, t=.75, p>.05), Interactivity (β = .02, t=.29, p>.05), and Ease of Use (β = .10, t=1.07, p>.05), do not have a direct impact on intention to use, rejecting H1, H2, H4, and H7. Finally, the results show a significant direct impact of Role of Guide on Intention to Ese (β = .61, t=9.5, p<.01), supporting H8. In addition, there is a significant direct impact of Multimedia and UI on Ease of Use (β = .44, t=8.56, p<.01), supporting H6. Figure 6.5 depicts the research framework, with regression coefficient values between the explored constructs.

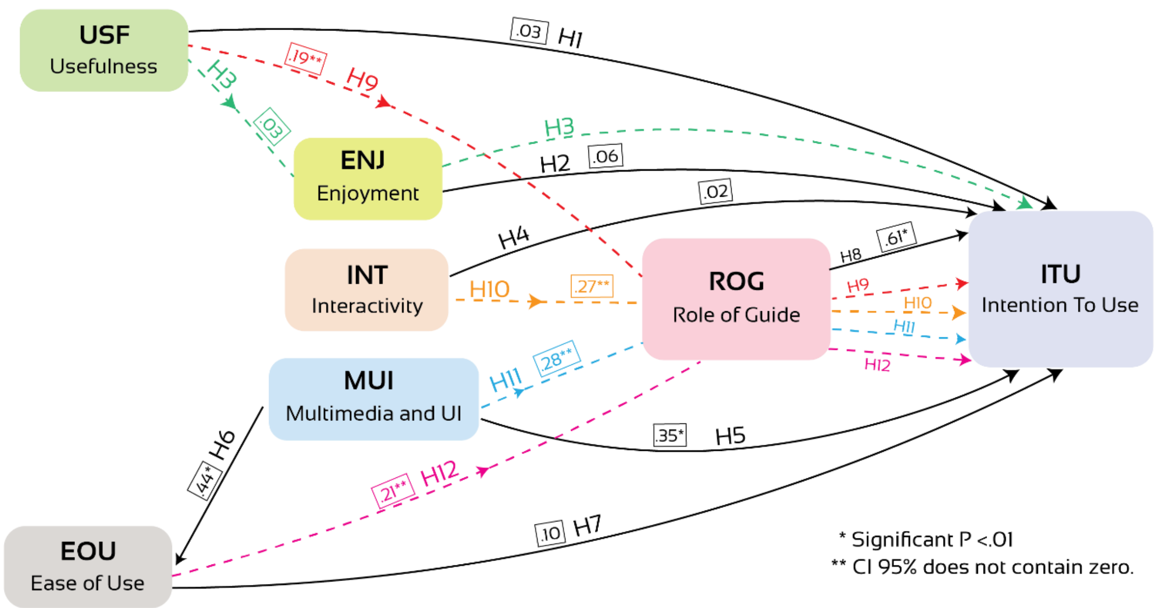

Figure 6.5 Theoretical Framework

6.2.3.3 Responses to Open-ended Questions

The participants were enthusiastic and positive in their responses to the open-ended questions. 122 out of 171 participants responded in their questionnaires. Table 6.6 shows the aspects that the participants consider the most significant. The responses could be classified into different themes; therefore, the table below analyses the qualitative responses quantitatively, by frequency. Moreover, Table 6.7 depicts the open questions that investigate the aspects which were not preferable and needed to be modified or enhanced.

Table 6.6 Participants' responses on open questions that explore the best aspects

What are the best aspects about MuseumEye?	Frequency
Enjoyment: *"The application was interesting, entertaining and engaging"*	15
Immersiveness: *"Isolation from surrounding people and the museum room and entering a pharaonic environment and the music helped me to make the experiment more immersive"*	16
Multimedia and UI: *"I like the graphics, images, music and the presentation manner"*	20
Role of being a guide: *"It can take the role of the museum guide or the labels' role and it gives me information on the issue I want to know about"*	6
Scenario and Storytelling: *"I want to see more storytelling and other contexts developed into MuseumEye."*	8
Usefulness: *"It contains beneficial information and very simple explanations"*	17
Ease of use: "*The system and very easy. It was very simple and I managed to navigate the system with an attractive way"*	14
Interaction: *"The navigation of the statues makes me feel that I was engaged more"*	18
Content is not distracting: *"The presentation of the king did not distract me out of the content of the museum"*	4
Independence: *"The visitor gets privacy", "More independency"*	7
Overall Satisfaction phrases: *"I like the idea and its implementation"*	12
The willingness of future use: *"I wish to see it permanently in the museum"*	4
Total	102

Table 6.7 Participants' responses to the aspects that need to be improved

What are other aspects, which are not so good about MuseumEye?	Frequency
FOV: *"Field of view was very narrow"*	5
Other language support: *"I wish to see the Arabic version"*	3
HoloLens weight: *"Little bit heavy"*	3
More Stories and more content: *"I wish I can see a menu that can list all the museum collections which have 100 antiques"*	4
Usability: *"Swiping and clicking is somehow cumbersome and need more instructions"*	5
Graphics and 3D models: *"The statue of Tutankhamun was not identical to the authentic one"*	6
Need more time to use: "The period of using it was so short"	3
Total	31

Based on the total results of the two previous tables, contribution to the best aspects questions was higher than questions relating to improvements, given it was 102 responses against 31. With a closer look to Table 6.6, the aspect the participants most had views on was 'Multimedia and UI', with 20 comments, followed by the 'Interaction' aspect with 18 comments. 'Usefulness' was mentioned 17 times and 'Enjoyment' aspect mentioned 15 times. Then, 'Ease of use' was mentioned 14 times, and finally, 'Role of being a Guide' was mentioned 6 times.

Regarding Table 6.7, which investigates the aspects that needed to be enhanced, 6 participants commented on how King Tutankhamun looked and compared him with the authentic statues of the king. Another group that comprised of 5 participants complained about the narrow field of view. Additionally, another group (also 5 participants) complained about difficulties with the interactions and the lack of instructions.

The open question results were other interpretations of the investigated aspects that were used to evaluate the efficiency of the MuseumEye as an information system. These different interpretations can present different angles of the participants' feedback, especially in terms of the effectiveness and the efficiency of the system.

6.2.4 Experts' Survey Analysis

In Table 6.8, the demographics of the experts are manifested based on their age group, expertise area and years of experience. Employing the experts for evaluation took into consideration the diversity of the disciplines of expertise that should be covered. 4 out of 9 experts were museum curators at the same museum. The experts consisted of 3 males and 6 females. 6 of the experts were between 31 and 45 years old, 2 were between 25 to 30 years old, and 1 expert was between 45 to 60 years old.

Table 6.8 Experts demographics

Discipline expertise	Male/ Female	Years of Experience	Age Group
Academic and professional expert in Visual communication and Arts	F	22	45 - 60
Expert at public engagement in museums	F	7	31 - 45
Expert in museum curatorship	M	7	25 - 30
Expert in museum curatorship	F	6	31 - 45
Expert in museum curatorship	F	4	25 - 30
Expert in HCI and visual interactions	F	9	31- 45
Data manager and responsible for enhancing the museum visitor engagement	F	2	31- 45
Expert in museum curatorship	M	10	31- 45
Academic and professional expert in museum curatorship	M	8	31 - 45

1- Content Validity

The evaluation process started by validating the MuseumEye's historical content and some comments were articulated regarding the validity of the content. Regarding its validity one participant said that 'g*enerally yes, although some details need to be edited'* and another expert suggested nothing was incorrect, stating, "*yes, as far as I know, based my knowledge of the subject*". Also, the validity of the content extended to cover images and audio representations. An expert commented that *"yes, they are relevant, but too straightforward and there needs to be more. At times, you need a more detailed graphical representation of the information to accompany the speech. The map and graphics were very simple,* *too simple"*. Moreover, another expert commented that the *"archive images are very good"*.

Additionally, the content validation explores the understandability and the obviousness of the narrator's language. One expert commented that the *"narrator is excellent*", however, another stated that *"the language is very clear. I did wonder about the use of colloquialisms, such as 'buddy'"*.

2- Tour design

The validation process involved the investigation of the design of the MuseumEye tour through three questions. The 1st question explored the logic of the stations' sequence. Regarding this, an expert stated that *"yes, it seems logical and appropriate, but it was somewhat difficult to locate the stations immediately"*. The 2nd question investigates the duration of the narratives in terms of whether it was adequate or not. Comments on this question varied between supporting it and suggesting that enhancements were required, as one expert commented, *"this seemed about the right length, but options to extend into more detail would be good"*. Another expert suggested a different way of enhancing the system, saying *"perhaps the intro could have a 'skip' option for those who want to cut straight into the interactive elements"*.

Concerning the 3rd question, which explores the suitability of the stations' location, the comment spaces provided reasonable questions as comments, which state *"How would this work with many people? Would there be queues for each spot? What happens when you are waiting?"*.

3- Usefulness

As a continuation of the validation process, the 1st question investigates whether the storytelling is clear or not, as one expert wrote, *"the welcome was essential. It got across the key information about whom the avatar represents. It was important to know his role as a guide in the museum and not a game character or an actor playing Pharaoh"*.

Regarding the 2nd question, which explores whether the storytelling covers the essential information or not, one expert commented, *"I would expect there to be more knowledge of Tut and his story than perhaps other aspects of the museum. It's a well-known story and I gauge the visitors' prior knowledge to be higher"*.

Concerning the 3rd question, which investigates whether the content demonstrates the essential information needed or not, one participant commented that *"the summary paragraph seemed about right in length and detail. There should be options later for more detail (even if directed to display boards in the museum) in the event of greater interest"*.

Regarding the 4th question, which explores whether the knowledge scale was beneficial or not, an expert commented that *"yes, it really helps to be able to see when all available information has been gleaned"*.

This was followed by the 5th question, which investigates the usefulness of the information revealed. One expert commented on this question that *"yes, the information was useful in terms of the materials it was made from and the texture - these are useful in a virtual representation"*.

4- Multimedia and UI Design

The validation of the system investigates the multimedia and the UI design aspect via three questions. The 1st question investigates whether the 3D characters (avatars) represent their Egyptian identities or not. An expert commented that *"they do, and it is very clear who they are; they are different, of different ages and colouring; this is helpful. I wanted to know more about the Anubis and Horus Avatars – you do introduce them, but it would be nice to meet them. Similarly, the guards – can we have a story from one of them?"*.

The 2nd question investigates the relevance of the historical music to Egyptian history. One expert commented that it *"seems appropriate, adds a sense of mystery and even tension and excitement "*. Also, another expert noted *"I think there is more that could be done here. There are experts on ancient Egyptian music. Showing the harps, flutes and percussion would give some further attention to this aspect. But what you did was good"*.

The 3rd question explored whether the 3D scanned antiques represent the authentic pieces or not. An expert commented that they *"felt very accurate as a representation of the objection question"*, and another expert emphasised the previous comment, saying *"this could slightly better reflect Tut objects/jewellery"*.

5- Ease of Use

The validation process involves the usability aspect, ensuring Ease of Use by questioning the experts with three questions. The 1st question investigates the comfortability of the headset. The first expert commented that *"it was a bit heavy on my neck, so I would not want it on too much longer. But the vision and sound were fantastic"*. Moreover, the other two comments were *"Not bad at all – Slightly heavy perhaps"*, and *"Little bit heavy"*.

The 2nd question explores if the user felt any medical problems during the usage of MuseumEye or not. One expert noted that *"the HoloLens was much better than VR headsets; there was no disorientation or loss of the horizon. I was immersed in the location without losing track of my surroundings. Good experience"*.

The 3rd question was concerned with looking around comfortably. There are two comments on this question, the first noting that *"I needed to think – and be reminded to look up and down"*, and the second comment stating that *"I felt I might like to zoom out a bit more"*.

6- Interactive Design

The interaction design was part of the validation process for the entire system. The 1st question investigated the ability to do the required interactivity by hand gestures. Comments varied between being positive about the ability such as "Yes, after minimal guidance", and other comments were a bit critical such as "It took a bit of practice", and "As for the first time to use it, I need more time to get used of it".

The 2nd question explored whether the interaction met the participants' expectations or not. One expert commented that it was a "*much more interactive than anticipated, loved that you can move around the scene and look in all* *directions*". However, some other comments were critical, as one participant said that "*it required some time to deal with it"* and *"when clicking on the left side I expected the photos and images to come on the left – which they did. When clicking on the right side I expected the photos and images to come on the right to preserve the symmetry, but they did not*".

The 3rd question investigated the ease of moving between scenes. Comments were very positive, as an expert noted that it was "*generally, very easy to use*" and another expert noted that "*this became easier the more I used the device*".

7- Role of a guide

Finally, the validation of experts explored the way MuseumEye can adopt the role of the museum guide. The 1st question asked regarding the system's usefulness as a guiding tool. There are two positive comments here, the first being *"yes, it certainly helps the users to gather additional info and to spend much longer with a piece of work/antiquity"* and the second comment was "*actually I want it more for the experience of a story in history*".

The 2nd question asked whether they believed that the application will be useful for guidance regarding the context of King Tutankhamun. One expert commented that *"there is a novelty in it and that will make it popular for a while, but it is what emotion you can breathe into the exhibits that will make it a long term success – the stories of the past, the feel of what it was like to be making a tomb, a guest in the palace, travelling through the flooded Nile fields or Egyptian market*". Moreover, another expert commented that *"I believe it adds really valuable elements to the knowledge gathering process. I don't think it will be appropriate to all visitors in all contexts, however as an optional interpretation resource it is an amazing powerful interpretation device".*

The 3rd question exploreed whether the application enhanced their understanding of the museums or not. The comments showed significant responses, such as *"I also believe that it will play a very significant role in helping to engage a younger audience, as it is hard to reach audiences in historical knowledge gathering in a museum. It will also help with visiting in general, which* *is incredibly valuable"*. Also, another expert wrote *"yes, with much more enhancement"*.

The 4th question investigated whether the system achieves touring independence for visitors or not. The comments here were more critical. One commented that *"yes, once people became familiar with the process of using the equipment. There is also an interesting question to consider here – arguably – about whether it affects people's ability to interact socially in the museum"*. On the contrary, another commented that *"it is scripted so they will follow it. It is not independent in that sense. But it does allow for a better flow of visitors and manages their time and route. Some people don't want to do it and will just want to wander from object to object"*.

The 5th question probes whether the experts can see the system replacing the tour guide or not. Comments varied between criticising the concept, stating that *"yes. Guidance and information will be in the book. This is a tour experience"*, and doubting the concept, saying that "*I am not sure. I am quite clear on the distraction being made here?"* and rejecting the concept, stating that the *"tour guide shall have a place – this is a complementary tool"*.

The 6th question explored the willingness and the need to see more storytelling in the system. These comments were quite positive and tended towards a desire to add more enhancements, requesting *"more stories from the individual characters. The option to go into more depth if you are interested and learn more about an object or historical event"*. Another comment also agreed with the previous one, saying *"more explanation will be beneficial to the visitors' experience especially in the King Tutankhamun exhibition"*. Two experts suggested a different approach to MuseumEye. One said, *"you can add activities or games for children"* and the other recommended *"games, and options to capture and share content e.g. photos"*.

As depicted in table 6.9, the overall mean values of the aspects were measured and evaluated by an expert as part of the validation process. The highest mean value was 4.42, which was for the Usefulness aspect, which implies that experts agreed strongly on the 'Usefulness' of the system in terms of it being used in museums. This was followed by, 'Ease of use', with a value of 4.29, then the Content Validity, with 4.25. The mean values that followed were quite high also, such as Tour Design, with a value of 4.22, Interactive Design, with a value of 4.14, then 'Role of being a guide' with a value of 4.11. The lowest mean value was 3.94, which was for 'Multimedia and UI design', which is also not considered a low value.

Table 6.9 Composition of the experts' evaluation constructs

Measure	Mean	Median	Std. dev.	No. of questions
Content Validity	4.25	4.33	.618	3
Tour Design	4.22	4.00	.400	3
Usefulness	4.42	4.60	.452	5
Multimedia and UI Design	3.96	4.00	.806	3
Ease of use	4.29	4.66	.654	3
Interactive Design	4.14	4.00	.765	3
Role of being a guide	4.11	4.00	.559	6

6.3 Observations

Table 6.10 presents the qualitative data collected through the observation activities.

Table 6.10 Observations of MuseumEye's user behaviour

<table>
<tr><th>N</th><th>Time spent on storytelling scenes</th><th>Number of portal points activated by the participant</th><th colspan="2">Time spent on exhibited items</th><th>Time spent gazing to the virtual guide ~=</th><th>Nature of behaviour</th><th>Overall duration by mins</th></tr>
<tr><td rowspan="4">1</td><td rowspan="4">1 min</td><td rowspan="4">4</td><td>60 sec</td><td rowspan="4">~= 1 min per item</td><td rowspan="4">17 sec</td><td rowspan="4">The participant kept focused, walked towards the scene portals, stopped by each and initiated scenes by himself. He asked for assistance during the hand interactions.</td><td rowspan="4">6 min</td></tr>
<tr><td>50 sec</td></tr>
<tr><td>55 sec</td></tr>
<tr><td>70 sec</td></tr>
<tr><td rowspan="2">2</td><td rowspan="2">3:37 min</td><td rowspan="2">2</td><td>107 sec</td><td rowspan="2">~= 2.5 min per item</td><td rowspan="2">20 sec</td><td rowspan="2">The participant was shown smiling and looking around herself. She faced crowds, but she kept looking and interacting. She asked for help during clicking buttons.</td><td rowspan="2">9 min</td></tr>
<tr><td>220 sec</td></tr>
<tr><td rowspan="3">3</td><td rowspan="3">3:15 min</td><td rowspan="3">3</td><td>120 sec</td><td rowspan="3">~= 2 min per item</td><td rowspan="3">25 sec</td><td rowspan="3">The participant moved freely with less assistance and moved her head around herself to discover visuals in the space. She smiled and looked excited when she triggered scenes.</td><td rowspan="3">13 min</td></tr>
<tr><td>150 sec</td></tr>
<tr><td>130 sec</td></tr>
</table>

N	Time spent on storytelling scenes	Number of portal points activated by the participant	Time spent on exhibited items		Time spent gazing to the virtual guide ~=	Nature of behaviour	Overall duration by mins
4	5 min	2	240 sec 230 sec	~= 4 min per item	90 sec	The participant showed an interest in doing the air tap in some situations, especially when she triggered a new scene. She asked for assistance at the middle of her tour.	18 min
5	6 min	2	88 sec 95 sec	~= 1.5 min per item	30 sec	The participant was not stable; he kept moving and spinning around himself and moving his head up and down to discover it fast. He also did not ask for assistance.	9 min
6	6:20 min	2	255 sec 280 sec	~= 4.5 min	45 sec	The participant asked for assistance on air tapping the first time only.	15 min
7	3:35 min	1	210 sec	~= 3.5 min	30 sec	The participant was tempted to do air tapping excessively, as a desire for more interactions. Fewer calls of assistance were requested.	7 min
8	3:10 min	2	150 sec 222 sec	~= 3 min	25 sec	The participant was witnessed smiling at the beginning of the application	5 min

N	Time spent on storytelling scenes	Number of portal points activated by the participant	Time spent on exhibited items		Time spent gazing to the virtual guide ~=	Nature of behaviour	Overall duration by mins
9	4:08 min	1	125 sec	~= 2 min	34 sec	The participant smiled at the beginning of the application then she stayed focused	6 min
10	2:13 min	1	110 sec	~= 2 min	26 sec	*No distinguished behaviour detected.	4 min
11	3:22 min	1	173 sec	~= 3 min	22 sec	The participant smiled when the application started.	5 min
12	3:12 min	1	154 sec	~= 2.5 min	19 sec	The participant smiles during the tour.	5 min
13	4:37 min	2	122 sec 132 sec	~= 1.5 min	45 sec	The participant seemed as if he was discovering the system and testing the functionality more than listening to the guide.	7 min
14	3:15 min	2	172 sec 135 sec	~= 2.5 min	34 sec	*No distinguished behaviour detected.	6 min

N	Time spent on storytelling scenes	Number of portal points activated by the participant	Time spent on exhibited items		Time spent gazing to the virtual guide ~=	Nature of behaviour	Overall duration by mins
15	3:02 min	2	182 sec 136 sec	~= 2.5 min	25 sec	The participant spoke to some tour peers during his tour, and he was excited. He seemed to be telling them what he could see at the moment.	5 min
16	2:50 min	1	119 sec	~= 2 min	23 sec	*No distinguished behaviour detected.	5 min
17	3:20 min	2	122 sec 183 sec	~= 2.5 min	50 sec	The participant smiled at the beginning and then after the storytelling finished, she asked for help and she made thumps up to her tour peers with a wide smile.	8 min
18	3 min	1	246 sec	~= 4 min	60 sec	The participant witnessed holding the HoloLens with one hand and she smiled at the middle of her tour.	7 min
19	4:14 min	2	243 sec 312 sec	~= 4.5 min	43 sec	The participant faced many people in front of her, but she did not feel disturbed and she kept listening and watching the visuals.	10 min

N	Time spent on storytelling scenes	Number of portal points activated by the participant	Time spent on exhibited items		Time spent gazing to the virtual guide ~=	Nature of behaviour	Overall duration by mins
20	4:33 min	1	214 sec	~= 3.5 min	32 sec	The participant was very excited, smiling and looking around everywhere and she started to speak to her peers.	8 min
21	6:44 min	3	130 sec 126 sec 144 sec	~= 2 min	20 sec	*No distinguished behaviour detected.	12 min
22	8 min	1	110 sec	~= 2 min	55 sec	*No distinguished behaviour detected.	10 min
23	5 min	1	123 sec	~= 2 min	45 sec	The participant moved in the hall in a wide circle and kept looking around to explore the blended environments.	7 min
24	4:40 min	1	254 sec	~= 4 min	65 sec	The participant kept moving forwards and backwards and did not ask for an assistant after the initial instructions.	10 min
25	3:20 min	1	114 sec	~= 2 min	12 sec	*No distinguished behaviour detected.	4 min

N	Time spent on storytelling scenes	Number of portal points activated by the participant	Time spent on exhibited items		Time spent gazing to the virtual guide ~=	Nature of behaviour	Overall duration by mins
26	4:44 min	1	56 sec	~= 1 min	15 sec	The participant smiled once the application started.	5 min
27	3:50 min	2	125 sec 65 sec	~= 1.5 min	21 sec	The participant was struggling with on hand interaction until she got the help she needed.	6 min
28	6 min	1	130	~= 1 min	13 sec	The participant was smiling during the presentation, and he took a selfie of himself wearing the headset.	8 min
29	3:57 min	1	156	~= 2.5	53 sec	*No distinguished behaviour detected.	6 min
30	4:21 min	1	92 sec	~= 1.5 min	15 sec	The participant kept looking around everywhere in a rapid manner to discover the visuals.	6 min
31	5:46 min	2	111 sec 423 sec	~= 8 min	10 sec	The participant asked for assistance during the tour.	13 min
32	4:10 min	1	235 sec	~= 4 min	72 sec	*No distinguished behaviour detected.	9 min

N	Time spent on storytelling scenes	Number of portal points activated by the participant	Time spent on exhibited items		Time spent gazing to the virtual guide ~=	Nature of behaviour	Overall duration by mins
33	3:52 min	2	125 sec 92 sec	~= 3.5 min	23 sec	*No distinguished behaviour detected.	7 min
34	3: 02 min	1	53 sec	~= 1 min	32 sec	The participant did not need assistance during the tour.	4 min
35	3:19 min	2	55 sec 123 sec	~= 1.5 min	26 sec	*No distinguished behaviour detected.	5 min
36	2:15 min	1	165 sec	~= 2.5	60 sec	Participant smiled when she took the device off her head.	5 min
37	5:20 min	2	192 sec 123 sec	~= 2.5 min	45 sec	The participant did not need assistance during the tour.	10 min
38	7:00 min	1	324 sec	~= 5 min	21 sec	The participant seemed to cope with the system quickly, and he did all the interactions needed after minimal interactions.	12 min

N	Time spent on storytelling scenes	Number of portal points activated by the participant	Time spent on exhibited items		Time spent gazing to the virtual guide ~=	Nature of behaviour	Overall duration by mins
39	6:36 min	3	233 sec	~= 4 min	53 sec	The participant seemed focused. He also moved between portals independently.	14 min
			260 sec				
			278 sec				
40	8:27 min	1	264 sec	~= 4 min	58 sec	*No distinguished behaviour detected.	13 min
41	6:19 min	2	146 sec	~= 2.5 min	63 sec	*No distinguished behaviour detected.	11 min
			176 sec				
42	5:37 min	1	275 sec	~= 4.5 min	50 sec	*No distinguished behaviour detected.	12 min
43	5:30 min	2	136 sec	~= 2 min	43 sec	The participant seemed more independent when she moved.	8 min
			123 sec				
44	7:00 min	1	432 sec	~= 7 min	35 sec	*No distinguished behaviour detected.	14 min

N	Time spent on storytelling scenes	Number of portal points activated by the participant	Time spent on exhibited items		Time spent gazing to the virtual guide ~=	Nature of behaviour	Overall duration by mins
45	5:44 min	1	375 sec	~= 6 min	47 sec	The participant frequently smiled during the tour	11 min
46	5:59 min	1	55 sec	~= 1 min	15 sec	*No distinguished behaviour detected.	7 min
47	6:20 min	1	342 sec	~= 4 min	32 sec	*No distinguished behaviour detected.	11 min
48	3:41 min	1	88 sec	~= 1 min	18 sec	*No distinguished behaviour detected.	5 min
49	5:16 min	1	305 sec	~= 5 min	100 sec	The participant seemed to be familiar with the system, and he managed to use it.	11 min
50	6:13 min	1	278 sec	~= 4.5 min	14 sec	*No distinguished behaviour detected.	11 min
51	5:37 min	2	254 sec 325 sec	~= 7 min	34 sec	*No distinguished behaviour detected.	14 min
Total	(1-8) min 6 min	(1-4)	173 sec per item	(1-8) min 3 min	(10-100) sec 36 sec		(4-18) 8.5 min

The measured parameters are divided into qualitative and quantitative results, wherein the latter was inherited from the observations as a qualitative tool.

Firstly, the quantitative results:

1- Time spent on the storytelling scenes: 51 participants spent from 1-8 minutes on the storytelling scenes with an average of 6 minutes.

2- Number of portal points activated by the participant: 51 participants activated 1 to 4 portals to enable the antique demonstrations and navigation ability.

3- Time spent on exhibited items: the average time a visitor spent in front of each exhibited item was 177 seconds (~= 3 minutes).

Holding Power index = $\frac{Avarage\ stopping\ time}{Utilisation\ time\ necessary}$ = 177 ÷ 90 = 1.96

'Holding Power' is measured by calculating the total time spent in front of an exhibit to measure the visitor's interest. This measurement informs the preliminary idea of the power of an exhibit to hold the interest of a visitor (Bitgood, 2017). Bollo and Dal Pozzolo (2005) stated that "the closer it is to 1, the greater the ability of the element to hold the visitors' attention will be".

4- Time spent gazing to the virtual guide: Based on the direction the participant turned to look, it was possible to identify that the visitor was looking at the virtual guide during the tour. Thus, it was not difficult to count the time that the visitor spent looking to the king, who acts as a virtual guide. Based on the results, the participant kept watching the virtual guide from 10 to 100 seconds, with an average of 36 seconds.

5- Overall duration: Finally, the overall duration of the MuseumEye experience was between 4 to 18 minutes with an average of 8.5 minutes in this specific room only.

Secondly, the quantitative results:

- Nature of behaviour: A few themes were captured. The first theme was that some participants seemed to be hesitant in using the system, especially with performing the hand interactions. Therefore, they asked for assistance during their tour. Regarding the second theme, the observational camera and the written notes captured that some of the participants were smiling before, during or after their tour. The third theme was that there were some participants who seemed familiar and confident with the system during the tour, as they did not ask for assistance and kept walking freely. The fourth theme revealed a group of participants who had the same attitude of exploring the environment and keeping moving around themselves to discover the surrounding virtual world. The fifth theme exposed a group of participants who accidentally faced crowds in front of their faces. This might obstruct the spatial visuals or cause issues with interactions' functionality, however, they seemed stable and engaged with the storytelling demonstrations. Furthermore, the sixth theme represented a group of participants who were witnessed talking and smiling to their peers as they were trying to inform them what they could see.

6.4 Discussion

After presenting the results and the analysis of the qualitative and quantitative data collection tools, which were conducted at the Egyptian Museum in Cairo to evaluate MuseumEye, this section demonstrates a discussion of the results according to the relevant literature.

6.4.1 Survey - Questionnaires

Demographics: According to the results of the participants' profiles, the differences in the age groups showed different levels of AR/VR awareness. According to Dean (2002), exposure to information systems in younger age groups is greater than adults. This was apparent in the results, which showed a higher awareness of the age group 18-25 in many perspectives. Then, the older age group 26-40 had a greater awareness than the oldest group, which was 41-60. These findings indicate that the level of acquiring computer skills and the willingness of using IT is greater in younger ages than older ages. However, 10% from the sample were above their 40s, who are a group sometimes known as 'silver surfers', according to Owen et al. (2005), and his group showed an adequate level of awareness and experience of AR/VR.

As stated in the results, the male participants showed a higher level of awareness and experience of AR/VR than the female participants, which agrees with what Owen et al. (2005) have claimed. Generally, the sampled participants showed a sufficient level of familiarity with the technology, which encouraged participants to embrace the technology during the experiment.

6.4.1.1 Descriptive Analysis

This section discusses the results of the measured aspects that evaluate MuseumEye quantitatively (Figure 4.3) and also discusses what themes were observed in the qualitative method.

1- Enjoyment

Most of the participants seemed to enjoy using the MuseumEye in the experimental museum tour. Initially, the existing problem that was found in the exploratory study was a lack of enjoyment, which can dramatically affect the length of time the visitors spend in the museum (Falk et al., 1998). After intervening the traditional touring methods with the MuseumEye system, it was expected to enrich the museum experience, with a sense of enjoyment and entertainment. Therefore, the mean value of the enjoyment aspect in the participants' evaluation resulted in 4.37 out of 5.0 as a maximum. Interestingly, the system's enjoyability was equivalent to other similar studies' results. One study resulted in 6.56 out of 7.0 as a maximum (Sylaiou et al., 2010) and another study resulted in 5.87 out of 7.0 as a maximum (Haugstvedt and Krogstie, 2012).

Moreover, 15 participants stated that *"the application was interesting, entertaining and engaging"* in the blank space for expressing their positive thoughts about the application. Also, the observation revealed a pattern of participants who were happy and smiling whilst wearing the headset and walking around the room. That was an obvious interpretation for the researcher to recognise which visitors were enjoying the tour. Another pattern of the visitors was witnessed talking and smiling to their peers as they were trying to inform them what they could see. This pattern was substantial proof of the participants enjoying and being engaged with their tours, not just individually, but also with their peers.

2- Usefulness

It was argued that the museum's pre-visit agendas included the desire for entertainment and gaining knowledge, which is considered an influencing motivation to come to museums (Falk et al., 1998). In return, disseminating information is one of the most integral roles of guides. Initially, the exploratory study revealed a lack of presenting adequate information to visitors, particularly in the labels and tags next to the exhibited antiques. MuseumEye was created to enrich visitors with information and change the mental image of the ancient Egyptian civilisation.

The evaluation investigated this aspect with the museum participants and the experts, which resulted in 4.37 out of 5.0 as a maximum and 4.42 of 5.0 as a maximum, respectively. The difference in results was not significant, as the experts responded slightly more positive than the museum visitors. These results can be compared with other studies, for example, MuseumEye's perceived usefulness involves better responses than the system devised by Haugstvedt and Krogstie (2012), which had a mean value of 5.20 out of 7.0 as a maximum. Moreover, it has better results than the system devised by Yilmaz (2016), which resulted in 4.30 as mean values out of 5.00 as a maximum.

Interestingly, 17 participants stated that there was *"beneficial information and very easy explanations"* in the open-ended questions. However, the experts suggested adding essential information to the main storytelling and gradually moving from superficial levels of knowledge to more advanced knowledge.

3- Tour Design

In the same way that tour guides draw their path lines and routes through the museum, the researcher was expected to design the tour that MuseumEye users follow and navigate in. However, this aspect was measured by the experts only. Due to the unique feature of spatial mapping and the virtual portals that are relevant to the exhibited antiques, the results were comparable with other studies that investigate the ability to navigate in the museum using different mediums. This aspect resulted in 4.22 as mean values out of 5.00 as a maximum. The responses were more positive than other studies, such as the study conducted by Naismith and Smith (2009) which resulted in 3.88 as mean values out of 5.00 as a maximum, and the study conducted by Naismith et al. (2005) which resulted in 2.71 out of 5.00 as a mean value. Also, in the observation activity, it was noticed that users moved freely from 1 to 4 portals including both the antique exploration and storytelling portals. This potentially proves the agility of MuseumEye, which does not disrupt the visitor from doing a natural tour that he/she desires.

However, the experts wondered about the way the system can handle bottlenecks that could occur due to many users targeting an interesting item at the same time. The system is designed to require space around the exhibited item, and the museum is required to widen the space around the exhibits in order to accommodate all users and their visuals.

4- Content Validity

Content Validity was measured only by the experts to validate the content and ensure its clarity for different types of visitors with diverse backgrounds. It resulted in 4.25 as a mean value out of 5.00. These results were more positive than other studies such as the study conducted by Carrozzino and Bergamasco (2010) which resulted in a response of 28% on this aspect. Another study (Bellotti et al., 2002) also showed fewer responses as it resulted in 48% on this aspect.

The experts also showed qualitative responses in the open-ended questions, as they positively reacted towards the validity of the content and they admired the simplicity of what can be conveyed via the visual content during the tour. However, they suggested improvements with more detailed graphical representation a criticised some wordings of the narrations to fit the context of the system.

5- Role of Guide

Role of Guide is the most vital aspect to be explored in this study, as this research contributes by introducing a replacement for existing guided tours with the mixed reality museum guide ‘MuseumEye’. This aspect was initially investigated in the museum and as demonstrated in the exploratory study, there was a significant lack of guided methods in the museum. In fact, this research created a new form of guide for mixed reality systems – detailed in section 2.6 – based on the literature review of museum guides and also according to the main roles of guides that were stated in earlier studies.

In the evaluation of the museum participants and experts, this aspect resulted in 4.38, 4.11 as mean values out of 5.00 as maximum, respectively. This can be compared with other studies that investigated similar aspects to the role of guides, which includes a study that measured how the guide helped visitors (Damala et al., 2008), which resulted in (mean = 3.1). Another study (Ghiani et al., 2009) measured the ability of the guide for presenting information with mean = 3.75. However, these studies could not measure the very same aspect of this study, given that the guide service provided here is more comprehensive in terms of its roles and abilities. The only study that can measure the service of guidance and its role - according to the old studies stated in chapter 2 - was a study by Zhang and Chow (2004) and it resulted mean = 4.32.

The study’s results show slightly lower responses from the experts when compared to the museum participants. However, they responded positively on some aspects, such as the way this application can help visitors to acquire information, motivating visitors to spend more time, the novelty of the system and if they expected the system to be popular and sustainable. They also admire the way the system can help the user gather information from the physical environment of the museum, along with its ability to engage younger visitors in overcoming the complexity of delivering a great deal of historical information in this context.

Despite these positive comments, there were some other arguments and critical comments that touched on the social interactions during the tour and the social isolation that could occur. However, the system can enable shared experiences between two or more users of the system, and in this case, social interaction might be encouraged. This aforementioned experience could not be achieved due to the limitations of the headset devices. Other comments probed into the way the system might distract users from the exhibits. However, our observations demonstrated that users kept gazing between the authentic items and the virtual objects. Also, the experts emphasised on adding more stories to the guide system and suggested making it suitable for younger ages.

6- Ease of Use

Results on Ease of Use from both the museum visitors and experts were positive. The visitors scored mean = 4.39, and experts scored mean = 4.29. For instance, 14 museum participants emphasised on the simplicity of the system and the ability to navigate in the museum. The experts had positive views on the device itself, comparing it with other immersive headsets, and noted that it does not have side effects, such as disorientation or making the user lose the horizon. The immersiveness of Microsoft HoloLens is a remarkable point that both participants and experts commented on. 16 visitors commented on how they were immersed in a pharaonic environment in this ancient time with the king and his guards.

However, 5 visitors and some experts complained about HoloLens' narrow field of view and said that it blocked their sight and made visuals fall in a narrow rectangle. 2 experts complained about the weight of HoloLens, but only 3 visitors mentioned this.

Comparing this aspect with similar studies, a study conducted by Damala et al. (2008) measured this aspect and resulted in mean = 3.08). Another study (Haugstvedt and Krogstie, 2012) measured Ease of Use and resulted in mean =5.01 in a 6-point Likert scale. Generally, this aspect showed more positive responses than other similar studies, which could stimulate users to adopt MuseumEye.

7- Multimedia and UI

Due to the uniqueness of the system's UI, as it was holographic and the visuals appeared to be floating on air, the users have to be exposed to an entirely new experience of interactions with this particular UI and the multimedia presented. Generally, the visitors were charmed with the technology of the headset and the way it presents the visuals that are placed around the users. They admired the way they interact with hand gestures and the way the images, videos, visual effects and the 3D sound are presented. 20 participants stated: *"I like the graphics, images, music and the presentation manner"*. The designed multimedia and Microsoft HoloLens itself helped the visitors to feel the immersion of the virtual environment, as mentioned previously.

Regarding the quantitative method, participants responded with mean = 4.33, however, the experts responded with mean = 3.96. This is due to some critical responses in terms of the way the multimedia represented King Tutankhamun and his queen. However, other experts have the opposite opinion about the aforementioned point, since they admired the colours, ages of the characters and the historical music.

Comparing this study's results with other relevant studies, a study conducted by Damala et al. (2008) measured the multimedia presentation at mean=3.16. Also, another study by Ghiani et al. (2009) investigated the effectiveness of the vocals, which resulted in mean = 3.67.

8- Interactivity

Interactivity involves the ability of the users to interact and get a response or feedback from the system. It was interesting to measure this aspect not only for the sake of the research, but also to ensure how this device can fit in museums. Additionally, this aspect investigates whether interaction with the system can divert attention from the exhibited items or not, as this is a crucial point of the system's evaluation.

The results presented responses from the museum participants (mean = 4.13) and experts (mean = 4.14). However, the experience was unique, especially in terms of the interactions with hand gestures. The responses were positive, as 18 participants commented that *"the navigation of the statues makes me feel that I was engaged more"*. Moreover, some experts were critical, as they stated that they needed more practice initially. Generally, the experiment involved a short tutorial about the methods of interaction and the way they should move to get better interaction experiences. Also, one of the observation patterns showed that some users hesitated, could not perform the interactions, and requested help from the researcher.

Comparing the results with other similar studies, one study (Bamberger and Tal, 2009) measured the interactions with the museum guide (mean = 3.95). Also, another study (Mantyjarvi et al., 2006) reported on the interaction ability (mean =3.0). As demonstrated here, the interaction satisfaction was positive, however, it might need a more clearer demonstration for visitors and might need more time to make the user more confident regarding the system's interactions.

9- Intention to use

intention to use was investigated after the exploratory study found that a previous guide tool had been suspended for use in the museum. So, it was crucial to investigate the sustainability of MuseumEye and ascertain whether the visitors were keen to use it in the future or not.

The results showed positive intentions for using it in the future, as 4 participants hoped to see more coverage of the museum's antiques not only the 10 items used in the present study. Another 4 participants wished to see it in the museum permanently. Moreover, 8 participants and some of the experts wanted to see more stories in the MuseumEye guide.

The quantitative evaluation conducted by the participants showed a willingness to use MuseumEye in the future (mean= 4.55). Comparing these results with similar studies, a study (Haugstvedt and Krogstie, 2012) investigated the behavioural intention regarding AR guide (mean = 4.3, maximum = 7). Another study (Chung et al., 2015) investigated the AR application in cultural heritage (mean=5.6), which is more equivalent to this study. Generally, the results were positive when compared with other studies, as this conclusion could indicate that visitors can accept using mixed reality system and potentially may pay for renting it before starting their tours.

6.4.1.1 Theoretical Framework

Generally, the results showed that Role of Guide mediates the relations between the other framework's constructs and intention to use. The Role of Guide strengthens the correlations between the constructs and intention to use and makes them more strongly significant. Moreover, not all the direct relations between the constructs and intention to use are significantly strong.

The perceived usefulness of MuseumEye does not influence intention to use directly, which does not agree with previous studies. However, perceived usefulness influences intention to use when the guide role mediates the relationship ($\beta = .19$, $R^2=0.27$, CI95% = .08, .33). However, it does not encourage intention to use when the perceived enjoyment mediates the relationship. This result can obviously highlight the significance of the guide role in MuseumEye. This outcome can go along with other similar studies as (Haugstvedt and Krogstie, 2012) resulted ($R^2=0.38$, $p<0.001$), (Lee et al., 2015) resulted ($\beta = .23$, $p<0.05$) and (Balog and Pribeanu, 2010) resulted ($\beta =0.24$, t value=2. 27, $p<0.05$). Due to the uniqueness of the relationship's nature in this study, it was not easy to find a similar study that measured indirect relationships that can embed mediators between the measured constructs.

With regards to perceived enjoyment, this study did not show a significant influence on the intention to use MuseumEye in the future. This result contradicts other studies (Haugstvedt and Krogstie, 2012) (Lee et al., 2015) and the reason being that perceived enjoyment might not be sufficient to be an intrinsic motivation for usage. If it was measured accompanying other constructs, it might increase the intention of future usage.

The perceived interaction with MuseumEye showed a less direct correlation with the intention to use the system in the future, however, it correlates significantly when the role of guide mediates the two constructs. This corrections also went along with other studies, as it resulted ($\beta = .27$, CI95%= .18, .40; $R^2=.44$) and a study done by Liu et al. (2010) resulted ($\beta = .12$, $p< 0.5$).

Multimedia and UI do not have a positive influence on the intention to use MuseumEye directly, but it does when the role of guide abilities mediate the relationship. The study showed higher correlations for the intention to use MuseumEye more than other studies, as it resulted ($\beta = .28$, $R^2=0.45$, CI95% = .16, .48). For instance, a study conducted by (Hong et al., 2011) that resulted ($\beta = .10$,

$p < 0.05$). This can indicate that when users engage with multimedia content and the UI, this can positively affect future usage.

Also, multimedia and UI has a strong influence on the perceived ease of use, as it resulted ($\beta = .44$, $t = 8.56$, $p < 0.01$). This also agreed with other studies (Liu et al., 2010), which resulted ($\beta = .47$, $p < 0.001$) and the study conducted by (Cho et al., 2009) which resulted ($\beta = .55$, $p < 0.001$). In fact, these correlations seem logical, since when the user feels familiar with the user interface, this would affect positively on the ease of using the system.

The perceived ease of using MuseumEye does not strongly influence the intention to use directly, however, it does when it mediates the two constructs. This means that the ease of using the system alongside the guide abilities can encourage the user to use the system in the future. The study resulted ($\beta = .21$, CI95%= .09, .39; $R^2 = .45$), which agrees with other studies such as one study conducted by (Haugstvedt and Krogstie, 2012), which resulted ($\beta = .15$, $t = 2.060$, $p < 0.05$), (Liu et al., 2010) resulted ($\beta = .12$, $p < 0.05$), and (Luarn and Lin, 2005), which resulted ($\beta = .33$, $t = 6.61$, $p < 0.01$).

Interestingly, the guide abilities among all functions of the MuseumEye system have the most substantial influence on the intention to use the system in museums, as it resulted ($\beta = .61$, $t=9.5$, $p<.01$). This can prove the significance of the role of guide on the intention to use among all other measured constructs. These statistics conclude that this system is initially designed to solve the guiding problem that exists in the targeted museum.

6.4.2 Observation

Time has been adopted as a robust and unobtrusive measure of museum visitors' attention (Falk, 1982, Serrell, 1995). The aim of designing MuseumEye and employing it in the Egyptian Museum in Cairo was achieved which extends the time that visitors spent in the museum. When comparing the results between the observation of the exploratory study and during the usage of the guide system, the Holding power increased from 0.4 to 1.96 respectively (from 40 seconds as an average to 177 seconds). According to Bollo and Dal Pozzolo (2005) *"The closer it* *is to 1, the greater the ability of the element to hold the visitors' attention will be".* Therefore, the system was able to draw visitors' attention to the visuals seen around the exhibited antiques and the interaction they had to perform to gain more knowledge.

Also, MuseumEye as a guide system can draw the attention of the three types of museum visitors: the greedy visitor, the selective visitor, and the busy visitor, which were categorised by Sparacino (2002).

However, the time measurement cannot always be an indication that the visitor is enjoying themselves since it might be an indication of struggling or facing difficulties (Serrell, 1997). This is the reason for combining qualitative and quantitative methods to ensure that time measures the level of enjoyment. The data collection methods gather data intentionally and non-intentionally to acquire a more profound insight into visitors' expressions during the tour.

Comparing the outcomes of the observation's statistics of this study with other studies that adopt technologies to extend visiting time, it was concluded that MuseumEye could extend the time much higher than other studies did. This study increased visting time by 440% compared to the time visitors used to stay in the same room. When reviewing other studies, it was found that a study was conducted by Proctor and Tellis (2003), who were able to extend the time spent from 45-minutes using portable audio to 55-minutes using a multimedia tour pilot. Another study also extended the time from 49.6 minutes without using guides to 59.3 minutes with using a museum guide (Lanir et al., 2013). Moreover, an old study (Robinson, 1928) aimed to extend the time spent using a pamphlet guide, which increased from 17 minutes (unguided) to 28 minutes (guided). Another project could extend the spent time from 5 minutes to 10 minutes using a mobile guide (Wang et al., 2009).

If MuseumEye was adopted by the museum and scaled to include numerous collections of the museum antiques, visitors could spend many hours, which could result in days worth of exploration, instead of approximately one hour in the regular visits.

6.4.3 MuseumEye vs. Human Guide

MuseumEye and human guides are compared in Table 6.11, according to the roles of guides defined by various scholars (Cohen, 1985, Holloway, 1981, Almagor, 1985) and recent studies (Goodwin, 2007, Zhang and Chow, 2004).

Table 6.11 Critical comparison between human guides and the MuseumEye guide

Role of Guide	Human Guide	MuseumEye Guide
'Pathfinder' (Cohen, 1985)	Pathfinding could be achieved effectively, and the guide can lead to interesting items in every hall and room sequentially. Also, he/she can create a pre-designed thematic tour starting from the entrance to the exit.	It could be applicable, however, the system was designed to give the visitor the choice to take the preferable scenario from the visitor's perspective. Also, MuseumEye can have the ability to give suggestions for the next recommended item to be visited. However, this functionality will be available on further developments.
'Mentor' (Cohen, 1985) (Best, 2012)	A human guide can more effectively be a personal tutor and a spiritual advisor in a more humanistic sense than other guide tools. Also, he/she can have a sense of humour and engage visitors in discussions to enlighten them about specific facts via face-to-face communications. Although this role is effective for human guide, guides could go away from the main topics or speak about restricted topics such as religion or politics, as explained in the exploratory study.	MuseumEye could be a mentor, but there are limitations in the ability of artificial intelligence to conduct face-to-face communication. Although it has this ability in some respects, it cannot do it effectively like a human. The MuseumEye system can represent the virtual guide as a human who can communicate to the visitors in one way of communication. It can enlighten visitors about facts, but it cannot go off topic, as the content is created professionally by museum experts
'Actor' (Holloway, 1981)	This role is achieved effectively if the human guide has rich experience in performing this act before, otherwise, he/she could have 'stage fright', which can affect negatively on the museum experience of visitors. The advantage of this role is in human interactions, which can make the human guide perform even better based on their level of confidence.	MuseumEye cannot suffer from 'stage fright' as it is a robotic performance and is pre-prepared and recorded by experts in studios. So, the virtual guide can be an actor, but it suffers (at this stage) from human communications.

Role of Guide	Human Guide	MuseumEye Guide
'Information-giver' (Holloway, 1981)	The human guide can perform this role effectively based on studying, practising and memorising the thematic tour he/she designed for his/her group. However, it is still limited due to human memory, and it is expected that the 'information greedy' visitors will ask questions that the guide cannot answer. It is a subjective ability and it can vary from a guide to guide based on his/her skills.	MuseumEye is an effective information-giver, as it can unlock levels of information based on the visitor's requests. It also can suit the three types of visitors that Sparacino (2002) suggested. The information is not limited to human memory like the human guide - the information is prepared and created by museum experts. Also, the quality of disseminating the information does not vary, which makes the system provide information at a constant level of quality.
'Leader' (Cohen, 1985)	This is a more social or humanist role, and human guides can perform it effectively depending on the personal skills of the guide. So, he/she is not only a pathfinder but also can be a leader in museum discussions, control the topic, control the time and inspire guests. However, this is not preferable for some types of visitors who desire to walk independently without being followed by someone.	Due to deficiencies in artificial intelligence at the time of creating the system, this social role is not quite applicable. However, it gives the visitor full control over timing, the flow of information and the location visited. It suits independent visitors who do not prefer to be led by someone.
'Teacher' (Holloway, 1981) (Fine and Speer, 1985)	This is a more social or humanist role, and the human guides can perform it effectively depending on the personal skills of the guide. It can work effectively with visitors of different age groups since the human guide can teach and provide information to kids differently to older ages	This role could be achieved, but not as effectively as the human guide, since it relies on human interactions. However, the content and the narrations could be created based on the age group of the visitor, so the way of teaching could vary based on the visitors' age, culture, and background. Although this function is not in the application at the moment, it could be included in further developments.
'Interpreter/Translator' (Almagor, 1985) (Holloway, 1981)	This role could be achieved effectively by the human guide as human guides can have the skills to speak multiple languages.	This role could be achieved effectively by MuseumEye. The system can interpret the information in many languages. This function is not present at the moment, but it could be

Role of Guide	Human Guide	MuseumEye Guide
		applicable in further developments.
'Caretaker' (Fine and Speer, 1985)	This role is more applicable in outdoor museums, where hazards might be present. However, the human guide can take care of the group he/she walks with and can ensure their safety until their tour ends.	Normally, MuseumEye is designed to work indoors, such as in museums and exhibitions. If there hazards present, MuseumEye can advise visitors and inform them of health and safety instructions. This feature can be considered in further developments.
'Ambassador' (Holloway, 1981)	The native human guide can act as an ambassador for his country and represent his/her culture to international visitors and further spread cultural information.	MuseumEye can act as an ambassador. Moreover, the virtual guide can be designed to act as one of the ancient people who lived in this period i.e. King Tutankhamun.
'Organiser' (Hughes, 1991)	The human guide can design his/her tour and organise it based on the time given by his/her visitors. This role does not fit the individual visitor who desires not to be led by a guide.	MuseumEye gives the user or the visitor the control to organise their time and the program of the tour. This role can fit the independent visitor and who walks individually.
'Culture-broker' (Holloway, 1981)	This role could be achieved effectively, as the human guide can introduce the culture physically or psychologically to international tourists.	MuseumEye can achieve this role effectively, as it can introduce the culture physically or psychologically to international tourists.
'Catalyst' (Holloway, 1981)	Human guides can perform this role efficiently, as it requires a higher level of human interaction.	This role is not applicable even if MuseumEye was running on the shared experience mode, as it requires a higher level of human interaction.
'Salesperson' (Fine and Speer, 1985)	Human guides can inform visitors to buy souvenirs from museum shops if they are interested.	MuseumEye can do this role and inform visitors to buy souvenirs. Absolutely, not in a humanistic way but it can do it interestingly.

6.5 Summary

This chapter presented the results, followed by an analysis and then a discussion. The results comprised the qualitative methods depicted in observations and quantitative results, which were represented by surveys/questionnaires. The discussion section addressed the results accompanied by relevant literature, with the aim of solving the research problem and highlighting the research contribution. The chapter ended by conducting a critical comparison of human guides and the MR guide ‘MuseumEye’.

Chapter 7: Conclusion

7.1 Introduction

Museum visitors have witnessed the introduction of various types of multimedia guides, e.g. audio guides, PDA, interactive screens, VR, AR, and robots, to ease and to enrich their experience in the past two decades. It is, therefore, time to further advance and transform museum halls and exhibits into a mixed environment of physical and virtual, using mixed reality technology. This can be considered a continuation of enriching the museum experience by using this facilitating, entertaining and useful medium. This chapter concludes with findings, theoretical and practical contributions and provides directions for future work.

7.2 Summary of the Thesis

This research was undertaken in the field of museum development and revealed a problem that exists at the Egyptian Museum in Cairo. This museum suffers from a lack of engagement that negatively influences the total time spent in rooms and the exhibition hall. Also, the museum lacks a full presentation of all information needed. Moreover, the only method of guidance the museum provides currently is human guides. The study started with a survey of the museum guides literature, which enabled the researcher to form a new approach to guide system that can be introduced conceptually and practically for this research as a solution. An exploratory study has been conducted to gain insight and collect data about the workaday tour guide activities. The exploratory study investigated the nature of visitors' behaviours in their tours through interviews and observations. The study considered the exploratory study and the literature review outputs as inputs for the proposed mixed reality system that can work as an alternative guide tool.

A HoloLens-based mixed reality system 'MuseumEye' was designed and developed following the methodology of design science research. MuseumEye could offer a number of functions that can facilitate both the individual and shared experience guidance abilities and can more deeply engage visitors with the museum context. The system used the spatial mapping technique and the 'Visual Information Visualisation Concept' for creating the spatial design of the museum room, which are blended with both physical and virtual objects. Also, the design phases introduced a new method of designing a spatial UI that can overcome the problem of the HoloLens' narrow FOV.

The system was evaluated using a combination of questionnaires (171 participants and 9 experts) and observation (51 participants) in the targeted museum. By comparing the observations in the exploratory study and the system evaluation, it was found that visitors who use MuseumEye spent four times the duration visitors spent without guides or with human guides in front of the exhibited items. The quantitative evaluation showed positive results among all measurements of MuseumEye compared with other studies. On a theoretical level, the study proposed a coherent theoretical framework that can evaluate the mixed reality guide in terms of its role of guide abilities, the perceived usefulness, the perceived enjoyment, ease of use, interactivity, multimedia and UI and the willingness of future use. The system showed a high desire for future use of MuseumEye in museums. Furthermore, the framework evaluation showed that without the role of guide factor, the system would not be promising for future use. The study concluded with a critical comparison between the role of guide for human guides and MuseumEye in order to show the pros and cons.

7.3 Research Objectives Revisited

- **To investigate the literature review and conduct an exploratory study of the targeted museum, with a view to exploring the optimum guide methods and roles in order to form a new taxonomy of guidance for the proposed system**

After surveying the literature of guide methods, including AR/MR that adopt the guiding abilities and the role of the guide that old studies emphasised on, a taxonomy of functions for a mixed reality guide system was determined. This taxonomy defined 9 characteristics of a full guide system, including all essential functions and roles of the guide. This full guide taxonomy ensures the abilities of museum guiding, being immersive, engaging, including contextualisation, personalisation, communicative and interactive, visual and audio augmentations, and provides social interactions. This taxonomy was formed not only to provide direction for MuseumEye but also for designers and developers who are involved in creating future mixed reality guide systems.

- **To design and develop an application that can be installed on a head-mounted display (Microsoft HoloLens) using MR technology to provide guidance in museum tours, via the aid of a personal virtual guide and visual interactive holograms.**

With the adoption of design science methodology, the mixed reality system using Human-Computer Interaction was designed with a set of functions that can facilitate and entertain the tour in the museum. Building the system went through several stages: the output data from exploratory study and literature review, system design, content creation, development process, and deployment and testing. The first stage investigated the visitors' behaviours, so some of the system functions were designed to accommodate for these behaviours. The second stage used the spatial mapping technique, so HoloLens was able to allocate all visuals in the museum room of study, with the direction of the generated concept 'Ambient Information visualisation concept'. The third stage involved creating several characters, environmental assets, and props to comprise the storytelling scenes and to achieve a sense of immersion. This stage also included designing a spatial UI after overcoming the limited FOV problem that HoloLens faces. The final stage involved the development of the system and ensuring all functionalities can work effectively without bugs or errors. The process of constructing this system was designed to provide guidelines for mixed reality developers, who intend to build guide systems either in a similar or different context.

- **To expand the time spent in front of exhibited items by engaging visitors in storytelling scenes and immersing them in interactive holograms that can motivate them to perform exploration activities with the exhibited antiques.**

This objective was achieved effectively, as the study involved two phases of observation methods. The first observation was conducted to reveal some facts about the museum under study, such as the time spent by regular visitors who either use guide methods or those who do not. Then, the second observation activity was conducted whilst experimenting with the MuseumEye system, which also revealed some further facts, such as the time spent, and the visitors' behaviours during the interactions. It was found that the average time visitors spent in front of the exhibited items using MuseumEye increased by four times the duration visitors spend with the human guide or without guide methods. Thus, it is believed that MuseumEye could significantly increase the level of engagement, and the museum experience is therefore holistically enhanced.

- **To develop a framework, which can evaluate the MR guide system in terms of the role of guide, perceived usefulness, ease of use, multimedia and UI, interactivity, perceived enjoyment and the willingness of future use.**

This objective was achieved by proposing a conceptual framework that involved adopting the technology acceptance model (Davis, 1985) to measure several factors such as the perceived usefulness, the perceived ease of use, and the user's behaviour towards using this system in the future. The quantitative method (surveys) was designed according to the factors of the framework. All factors were adopted from the extant literature, except for the role of guide factor, which was introduced in this study. Thus, an exploratory factor analysis was conducted to explore the factors among the other factors. Then a confirmatory factor analysis was conducted in order to confirm the measurement theory.

The hypothesis showed significant correlations between the measured factors and therefore reliability was achieved. The results of the evaluation according to the proposed framework showed strong correlations between all factors and the willingness of future use factor, only when the role of guide mediated the relations. However, the direct relations between most of the factors with the willingness of future use were weak. Therefore, this means that the Role of Guide is the most crucial factor that stimulates intention to use in the future.

The framework introduced in this study is the first conceptual framework that can measure the role of guide factor in mixed reality systems among relevant significant factors, and the willingness of future use by museum users is to be expected.

7.4 Contributions and Implications

7.4.1 Contributions

<u>Theoretical Contributions</u>:

- **This study introduces a mixed reality guide form that can enhance and reshape the museum experience.**

The museum experience, according to Falk and Dierking (2016) comprises three essential components: the personal context, the sociocultural context, and the physical context. MuseumEye, as an MR guide system, could enhance and reshape the three components. Firstly, the personal context is the visitor's agenda for coming to the museum, which includes their preferred way of acquiring knowledge, interests, how he/she behaves and what he/she needs. Accordingly, this study acquired a thorough understanding of what this particular visitor needs, or how they behaved, which is reflected in the designed system. Then, the evaluation process demonstrated that these needs were fulfilled with some quantitative measures, such as perceived usefulness and perceived enjoyment.

Secondly, the sociocultural context is represented as the cultural background of the visitor, accompanied by social factors such as who walks with the visitor in the museum. MuseumEye's contextual virtual guide is designed to accompany the visitor during the tour and enrich him/her with the required cultural and historical information. It also allows sharing the experience with peers simultaneously, if they activate this function. Thirdly, there is the physical context, which is basically the museum setting, which influences the visitor accordingly based on the museum experience. MuseumEye, as a mixed reality system, used the spatial mapping technique to blend between the virtual and physical world in the museum room. Moreover, the system displays holograms of virtual replicas and user interfaces. Thus, these visualisation techniques could change the perception of the museum settings. According to what was discussed, MuseumEye proved that it can enhance and reshape the museum experience of museum visitors.

This study agrees with other relevant studies that aimed to enhance the museum experience (Pedersen et al., 2017), however, it was more of an educational tool than a guide, and it cannot support touring in the museum. Another study (tom Dieck et al., 2018) aimed to enhance the learning experience, however, it was also not considered a guided system. In addition, their AR system worked very differently to MuseumEye. There was another relevant study that could change the museum experience (Dionisio et al., 2018), however this change was in terms of extending the museum experience into a neighbourhood surrounding. Moreover, it was designed not to be a museum guide and it used mixed reality, which works differently than MuseumEye since it uses a mobile device instead of a wearable device.

- **A theoretical framework which assesses MR guidance system in terms of perceived usefulness, enjoyment, ease of use, interactivity and their relations to the likelihood of future use.**

Many studies constructed frameworks for museum guides in terms of the satisfaction of using specific functions (Pavlidis, 2018) (Loboda et al., 2018), and others built frameworks for achieving the UX in museums (Liu and Idris, 2018), or to design AR museum guides (Rodrigues et al., 2018). However, there has been no study that incorporated the willingness of future use with the role of guiding and demonstrated a relationship between them.

This study constructed a theoretical framework, which comprises several concepts from the literature review that are relevant to using information systems. Also, this framework measured a new factor 'role of the guide', as it was neglected and not measured in the earlier AR or VR museum guide systems. The framework adopted some factors that are relevant to using information systems from the Technology Acceptance Model, introduced by Davis (1985). Additionally, some other factors that are relevant to the museum experience were integrated into the framework in order to offer holistic representations of the mixed reality guide system. Holographic mixed reality is a recent technology for museums (Pedersen et al., 2017) (Pollalis et al., 2017), so the nature of these guides needs to be measured technologically regarding its usability and the willingness of future use, and conceptually regarding the museum experience, it needs to be measured in terms of usefulness, being guided, and the perceived enjoyment.

- **The perceived guiding is the most effective factor that can stimulate the likelihood of future use of the mixed reality museum guides.**

Several studies conducted evaluations on museum guides to assess the intention to use factor (Goren-Bar et al., 2006) (Rocchi et al., 2006) (Oh et al., 2009) (Lanir et al., 2011). However, the uniqueness of this study is in hypothesising the correlation between perceived guiding, the 'role of the guide' and 'the intention to use', which was significantly positive.

According to the quantitative study that this study conducted based on the proposed framework, it was shown that the strongest correlation was found between perceived guiding and willingness of future use, among all other factors, such as perceived usefulness, ease of use, perceived enjoyment, multimedia and UI and interactivity. Moreover, most of the direct correlations between the measured factors and the willingness of future use are weak, unless the role of guide mediates these relations, then it became stronger. This study proved that designing the guide system according to the main roles of guides that are stated in the most cited museum studies can stimulate the visitors' intention to use the system in the future.

Practical Contributions:

- **Introducing the Ambient Information Visualisation Concept (AIVC) for increasing visitor engagement by better presenting information and enhancing communication and interaction between visitors and exhibits.**

This study contributes practically through developing the concept of ambient information visualisation, exploiting the technical features of spatial mapping that Microsoft HoloLens can perform. This concept was developed from several concepts in the literature of information visualisation methods (Skog et al., 2003) and casual information (Pousman et al., 2007). Ambient information visualisation has the potential to immerse the museum visitor in a new and highly captivating informational experience. Furthermore, this concept permits visitors to visually engage with virtual artefacts in a less restricted environment that the physical space allows for (Hallnäs and Redström, 2002). This concept also can aid spatial designers practically to design the museum room to fit the storytelling scenes that comprise virtual and physical objects and environments. This concept was designed to be user-centred rather than device-centred, so it places the user in the middle of the entire design space.

- **A mixed reality guidance system was designed and developed to reshapes museum space, to enhance visitors' experience and to significantly increase the length of time they spend in the museum.**

Although there are some studies that exploited museum guided methods to expand the time spent in museums (Robinson, 1928) (Lanir et al., 2013) (Proctor and Tellis, 2003) (Wang et al., 2009), there has been no study that has shown the potential of expanding visiting time using mixed reality guide system. Moreover, as previously mentioned, the amount of time spent was expanded four times in the present study.

The main problem of this research is a lack of engagement that the museum of the study suffers from, as visitors spend one single hour on average in the museum, including all rooms and halls. According to the exploratory study that this research conducted on the average time the visitor spent in the same museum (either guided with human guides or non-guided), visitors spent only 40 seconds in front of every single exhibited antique. MuseumEye aimed to stimulate the engagement level and makes visitors stay more and grasp more information, interact and be guided by the MR virtual guide. After conducting an observation data collection method, it was found that visitors spent 4 times the duration they usually spent in the same room.

7.4.2 Thesis Implications

This study can open the prospects for mixed reality to invade museums and the cultural heritage sector and it takes the traditional museum experience to a new level of engagement and interactive experience. The expansion of visiting time that resulted due to using MuseumEye in museums can allow visitors to stay in the museum for more than one hour, which could potentially become several hours or even days. This has implications on the number of other services the visitors can use, such as gift shops, the café and other facilities that can increase the income of the museum annually. The MR technique, which is currently deployed in museums, could be an important vehicle for driving the tourism industry towards achieving success, and thus this might directly reflect on Egypt's economy.

Through adopting the technology, the awareness of the wearable technology and the ability to interact with holograms will be familiar in the context of museums and cultural heritage. It is especially relevant when trying to reach the younger Egyptian generations, through using new technology that creates rich, fun and engaging experiences for visitors, rather than touring in a traditional method. This method enriches the historical knowledge of both native and non-native visitors.

This thesis also introduces a road map for museum guide designers, developers, and academics who desire to adopt mixed reality holographic technology for using it in museum rooms. It also demonstrates guidelines and directions for creating different types of visual content (images, text, audio, video and 3D holograms) to be included in the museum guide using Microsoft HoloLens.

This project also introduces an initiative to preserve the heritage and the antiques inside museums digitally, by scanning the targeted antiques in 3D holograms in order to enhance visualisation and increase accessibility for the visitors. MuseumEye could, therefore, have an obvious influence on tourism in Egypt, and encourage tourists to come and engage with this unique museum experience, and this correspondingly can influence positively on Egypt's national income.

7.5 Future Work

This section provides directions for researchers who desire to conduct further research on Mixed Reality guides in museums and the cultural heritage sector:

- Future development of MuseumEye will take into account what the museum experts commented on or criticised in the evaluation stage regarding the system functionalities, visuals, or the conceptual roles of the guide.
- Further research into exploratory studies should consider expanding the sample size of the semi-structured interviews (n=10), however, it was satisfactory according to Steinar (1996). Employing more participants can reveal more information about human guide performances and how visitors are satisfied (or not) with the service provided.
- There are some hypotheses that investigate the correlations between the other factors that this study did not explore such as: the influence of interactivity on perceived enjoyment, the influence of multimedia and UI on the perceived enjoyment, and the influence of perceived enjoyment on ease of use.
- There is potential not only for academics but also for practitioners to explore more functions provided by Microsoft HoloLens or other upcoming devices such as Apple smart glasses (Statt, 2018), Magic Leaps (Magic Leap, 2018) or Leap Motion – North star project (Holz, 2018). These new eyewear/headset devices could have an unexpected potential for museum guides that have a mobility nature.
- Future research could involve an exploration of functionalities such as; the shared visual and interactive experience in museums. This can potentially

reveal more social interactions with peers who used similar headsets. Thus, critical comparisons could be made to investigate the social factor of the MuseumEye virtual guide and the other guide methods.

- Due to revealing the second version of Microsoft HoloLens regarding the incorporation of the artificial intelligence (AI) (Pollefeys, 2017) (Goode, 2019), there is the potential to utilise these AI abilities with museum virtual guides. This is could be more than promising, as it might enrich communication and interactions between visitors and the virtual guide. This also can reveal unexpected responses from visitors, which could correspondingly reshape the museum experience in another perspective.

7.6 The Future of Technology in Museums

The digital revolution's next few years can change the static form of museums. It will not just be a place to showcase antiques from different ages, it will be a time machine for travelling into different periods of time and the technology has a vital role to achieve this transformation. Technology can be applied in different approaches:

- VR Live shows: This approach can be achieved by a real-time VR system that involves a human actor wearing a motion capture suit and a VR headset, and in the other side the visitors can wear the headset to see this actor but as a historical avatar e.g. ancient king. Then a real performance with direct communication can occur between the visitor and the performer within a virtual world (Figure 7.1).

Figure 7.1 Image demonstrating the VR Live show – concept (Teslasuit, 2019)

- Holographic live shows: At a certain point, technology will stop requiring users to wear devices on their heads or eyes. Instead, holograms can be projected within the physical space by real holographic devices that can be seen without additional technological mediums (Ropers, 2019). With the integration of artificial intelligence, the holographic avatars could be made to speak and interact with visitors. Thus, the technology then can create a glimpse of an ancient life and turn the museum room into an exciting place with blended realities. The museums at this stage will no longer be conventional places to exhibit, they become portals to other interesting worlds.

- Interactive games: Based on the previous approach, many activities can be held in museum rooms to boost the attraction levels in museums (Smith et al., 2019). Interactive holographic games can be designed to be played within the museum, based on quests that can be requested from visitors e.g. collect relevant relics or shooting historical villains.

- Virtual Museums: Mixed reality devices are constantly evolving and will be produced massively as discussed earlier. According to this optimistic approach, visitors around the world can bring museums into their homes virtually and interact with the virtual exhibits and listen to storytelling in a manner similar to the real experience.

- Multi-sensory experience: According to the evolving multi-sensory technology (Cruz-Hernandez et al., 2019), it is expected, in few years, that users can use haptic sensors to feel the surfaces of the exhibited relics but in a virtual context. It even may exceed these limits and enable users to smell and use different senses.

These possible approaches could lead to an increase in the level of engagement in museums and reshape the current perception of museums to another form. These directions can also influence and enrich the aesthetical, cultural and historical aspects of the daily visitors.

7.7 Epilogue

This chapter presented the main findings of the research, summarising the theoretical and practical contributions, limitations and it has further suggested future work for researchers and developers of immersive reality for museums and historical places.

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Appendixes

Appendix A. Comparison Between HMDs Specs

In the following table, a thorough comparison between all of the mentioned gadgets based on their specifications.

Table A Comparison between Hardware specifications of HMDs or eyewear in the market

Specifications	Magic Leap	ODG- R7	Epson Moverio BT 300	Meta 2 Glasses	Microsoft HoloLens
System	Android 5.0	Android 4.4	Android 5.1 Marshmallow	Windows 8.1 64-bit or newer	Windows 10
Display	1280 x 960	1080p	1280x 720 Resolution	2550x1440 resolution	2 HD 16:9
Battery life in active mode	3 hours	2-3 hours	6 hours	No batteries	2-3 hours
Weight	345 g	125 g	69 g without light, shielding / harness or cables	420 g	579 g
Field of View	30° x 17.5°	30° (Renner and Pfeiffer, 2017)	23°	90° diagonally (Renner and Pfeiffer, 2017)	30° x 17.5° (Keighrey et al., 2017)
Processor	Quad-core Marvell ARM	2.7GHz Quad-core	Quad core Intel Atom X5	Requires a PC with Intel Core i7	Intel Atom x5-Z8100 1.04 GHz + 4 Logical Processors
RAM	8 GB	3GB DDR3	2 GB	Requires a PC with 4-8 GB	2 GB
Camera	1 MP	4 MP	5 MP	720p front-facing camera	12 MP
Storage	128 GB	64 GB	16 GB	Requires a PC with 10 GB	64 GB
GPS	No	Yes	Yes	No	No
Gyroscope	Yes	Yes	Yes	Yes	Yes
Accelerometer	Yes	Yes	Yes	Yes	Yes
Magnetometer	Yes	Yes	Yes	Yes	Yes
Gesture recognition	No	No	No	Yes	Yes

Appendix B. Comparison Between AR, VR and MR Apps

Table B, demonstrates a comparative analysis of recent studies that implement HMDs in museum applications. This table includes the 'MuseumEye', an MR prototype developed for this study to demonstrate its systematic abilities alongside other comparable systems.

Table B. A comparative study of Projects that used VR, AR and MR HMDs

Project's Name	VR/ AR	Mobility	Interactions in two ways	On-location storytelling	interactive game	The sense of virtual/mixed Environments	3D spatial multimedia representation	Museum Guidance	Shared Experience
Meta Museum **(Mase et al., 1996)**	VR	X	√	X	X	video capturing degrades the sense of reality	On computer display	√	X
Matrix **(Rekimoto, 1998)**	VR	√ wired and bulky	X (one way)	X	X	√	√	√	X
SHAPE **(Hall et al., 2001)**	AR	√ with Laptop	√	√	X	X Virtual and real worlds are not mapped together	X	√	X
Empty Museum **(Hernández et al., 2002)**	VR	√ with Laptop	√	X	X	X Only virtual worlds	X	X	√
The Museum Wearable **(Sparacino, 2002)**	AR	√ with Laptop and keyboard	√	√	X	√	√	√	X
ARCHEO-GUIDE **(Vlahakis et al., 2002)**	AR	√ with Laptop	X (one way)	√	X	√	√	√	X
TableTopAR **(White et al., 2003)**	AR	X	X (one way)	X	X	√	X	X	X

MR SEA CREATURES **(Hughes et al., 2004)**	AR	X	√	√	√	√	√	X	√
MiRA **(Holz et al., 2006)**	AR	√	√	√	X	√	√	√	X
3-D Museum Guide **(Okuma et al., 2007)**	None	√ with Hand-held PC	X (one way)	X	X	X	X On handheld PC	√	X
Museum Guide Through Annotations **(Aracena-Pizarro and Mamani-Castro, 2010)**	AR	√	X (one way)	X	X	X	√	√	X
Digital Display Case **(Kajinami et al., 2010)**	None	√	X (one way)	√	X	X	X	√	X
Wide FOV Displays **(Yamazaki et al., 2010)**	VR	X	X (one way)	√	X	X	√	X	X
ARbInI **(Dierker et al., 2011)**	AR	X	X (one way)	X	X	√	X	X	X
ARtSENSE **(Schuchert et al., 2012)**	AR	√	√	√	X	√	√	√	X
Cypriot CH **(Loizides et al., 2014)**	VR	X	√	X	X	X Only virtual worlds	X	√	X
Santa Maria Project **(Fineschi and Pozzebon, 2015)**	VR	X	√	X	X	X Only virtual worlds	X	√	X
World War I **(Moesgaard et al., 2015)**	VR	X	√	X	X	X Only virtual worlds	X	X	X

Mobile VR **(Papaefthymiou et al., 2015)**	VR	X	√	X	X	X Only virtual worlds	X	X	X
3DCG **(Soga, 2015)**	VR	X	X	X	X	X Only virtual worlds	X	X	X
MR Museum **(Zhang et al., 2016)**	AR	X	√	√	X	√	√	√	X
Seokguram Grotto **(Zhang et al., 2016)**	VR	X	√	X	X	X Only virtual worlds	X	X	X
MuseumEye	MR	√	√	√	√	√	√	√	√

Appendix C. Museum Experts' Survey Questionnaire

MICROSOFT HOLOLENS APPLICATION 'MUSEUMEYE' VALIDITY QUESTIONNAIRE

Thank you for participating in the assessment stage of 'MuseumEye'. Your feedback is crucial in the structure, content, and guided tour design validity, along with inter-rater reliability of the AR museum guidance tool.

Once you have used 'MuseumEye', please complete the following questionnaire. Each question is accompanied by a 5-point Likert Scale, which measure the likeliness of the statement. Ratings are made on a numerical scale from 1 to 5.

At the end of every question, a comments section/blank space is provided for you to express your opinion, make comments and justify your choices. You are strongly encouraged to use this space. Additional paper can be provided if you request it.

This questionnaire is divided into 5 sections for you to complete:
1. The content
2. The tour design
3. The multimedia design
4. The usability and interactivity
5. The role within current guidance

This questionnaire will take approximately 20 minutes to complete, and depends on the depth of your feedback.

1. The content:

This part of the study is for you to test the quality of the content in the application.

1. The storytelling of King Tutankhamun is straightforward, clear and simple.

Strongly Disagree	Disagree	Neither	Agree	Strongly Agree
1	2	3	4	5

Comments:

2. The content of the storytelling covered most of the essential information .

Strongly Disagree	Disagree	Neither	Agree	Strongly Agree
1	2	3	4	5

Comments:

3. The content of the stories is historically accurate .

Strongly Disagree	Disagree	Neither	Agree	Strongly Agree
1	2	3	4	5

Comments:

4. MuseumEye presents most of the essential information of the displayed item.

Strongly Disagree	Disagree	Neither	Agree	Strongly Agree
1	2	3	4	5

Comments:

5. Images presented during the narration was relevant and straightforward.

Strongly Disagree	Disagree	Neither	Agree	Strongly Agree
1	2	3	4	5

Comments:

6. The narrator's language is clear and understandable.

Strongly Disagree	Disagree	Neither	Agree	Strongly Agree
1	2	3	4	5

Comments:

7. The knowledge scale is beneficial and stimulating the visitor to gain information

Strongly Disagree	Disagree	Neither	Agree	Strongly Agree
1	2	3	4	5

Comments:

8. The revealed information from yellow circles is useful .

Strongly Disagree	Disagree	Neither	Agree	Strongly Agree
1	2	3	4	5

Comments:

9. Is there anything that was missed in application which you would like to be added?

2. The tour design:

This part of the study is for you to test the validity of the tour design in the application.

1. The order of station 1, 2 and 3 is appropriate .

Strongly Disagree	Disagree	Neither	Agree	Strongly Agree
1	2	3	4	5

Comments:

2. The duration of the narrative of each scene is adequate.

Strongly Disagree	Disagree	Neither	Agree	Strongly Agree
1	2	3	4	5

Comments:

3. The location of stations 1,2 and 3 are appropriate for the sake of tour design and not confusing the visitor.

Strongly Disagree	Disagree	Neither	Agree	Strongly Agree
1	2	3	4	5

Comments:

4. Is there any principles of tour design which was missed or which you think needs to be added/improved in the application?

3. The multimedia design:

This part of the study is for you to test the relevance of the multimedia design to the historical context in the application.

1. The 3D characters (avatars) are representing the ancient Egypt identity.

Strongly Disagree	Disagree	Neither	Agree	Strongly Agree
1	2	3	4	5

Comments:

2. The historical background music is relevant to the ancient Egyptian context.

Strongly Disagree	Disagree	Neither	Agree	Strongly Agree
1	2	3	4	5

Comments:

3. The 3D scanned antiques (virtual replica) is representing the authentic pieces.

Strongly Disagree	Disagree	Neither	Agree	Strongly Agree
1	2	3	4	5

Comments:

4. Is there any idea you want to add to the multimedia design which was missed or which you think needs to be added/improved in the application?

4. The usability and Interactivity:

This part of the study is for you to test the usability of the application.

1. I found the headset comfortable to wear throughout the application usage.

Strongly Disagree	Disagree	Neither	Agree	Strongly Agree
1	2	3	4	5

Comments:

2. I did not experience nausea, dizziness, or headache using the 'MuseumEye' application

Strongly Disagree	Disagree	Neither	Agree	Strongly Agree
1	2	3	4	5

Comments:

3. I could look around the room comfortably, without any discomfort

Strongly Disagree	Disagree	Neither	Agree	Strongly Agree
1	2	3	4	5

Comments:

4. I could do air tap on the virtual objects appropriately (hand gesture)

Strongly Disagree	Disagree	Neither	Agree	Strongly Agree
1	2	3	4	5

Comments:

5. I could interact with the user interface as I expected.

Strongly Disagree	Disagree	Neither	Agree	Strongly Agree
1	2	3	4	5

Comments:

6. I could move between scene easily.

Strongly Disagree	Disagree	Neither	Agree	Strongly Agree
1	2	3	4	5

Comments:

7. The revealed information from yellow circles is useful .

Strongly Disagree	Disagree	Neither	Agree	Strongly Agree
1	2	3	4	5

Comments:

8. Is there something that you want to share about the usability, but we missed asking you?

5. The role within current museum guidance:

This part of the questionnaire tests the value, usefulness, and possibilities of the MuseumEye application in guiding visitors in museums.

1. I found this application interesting

Strongly Disagree	Disagree	Neither	Agree	Strongly Agree
1	2	3	4	5

Comments:

2. I found this application will be useful for guidance regarding the context of King Tutankhamun.

Strongly Disagree	Disagree	Neither	Agree	Strongly Agree
1	2	3	4	5

Comments

3. Addition of augmented reality applications like Microsoft HoloLens apps to the museum guidance will be beneficial for visitors in museums

Strongly Disagree	Disagree	Neither	Agree	Strongly Agree
1	2	3	4	5

Comments

4. I think this application will enhance the understanding of museumc visitors regarding the story of king Tutankhamun and his collection.

Strongly Disagree	Disagree	Neither	Agree	Strongly Agree
1	2	3	4	5

Comments:

5. I think visitors will be more independent in their tours by using this application.

Strongly Disagree	Disagree	Neither	Agree	Strongly Agree
1	2	3	4	5

Comments:

6. I see this application more like a tour guide than a necessary tool for guidance

Strongly Disagree	Disagree	Neither	Agree	Strongly Agree
1	2	3	4	5

Comments:

7. I want to see more storytelling and other contexts developed into MuseumEye

Strongly Disagree	Disagree	Neither	Agree	Strongly Agree
1	2	3	4	5

Comments:

8. Are there any non-technical/cognitive features that you would like MuseumEye to add aside of the existing role(guide visitors)? (e.g. Games, Q&A, taking pictures, more explaination)

9. What are the best aspects you like about MuseumEye?

10. What are the not so good aspects about MuseumEye which are needed to be improved?

End of questionnaire. Thank you for your participation, - please inform a researcher you have finished. If you have any more feedback or questions regarding the dissemination of your data, please contact the researcher by the following methods:

Appendix D. Museum Participants' Survey Questionnaire

MIXED REALITY HEADSET GUIDES IN HISTORICAL MUSEUMS SURVEY- PRETOURING

Section 1# Background Information

1- Age : ◯ 18 - 25 ◯ 26 - 40 ◯ 41 - 60 ◯ Above 60

2- Gender : ◯ Male ◯ Female ◯ Other ◯ Prefer not to say

Section 2# Guiding in museums

5- Are you following a tour guide? ◯ Yes ◯ No

(If it is No please answer the next questions)

6- To what extent you feel you are in a need of tour guide?

◯ Strongly don't need ◯ Don't need ◯ Neutral ◯ I need ◯ Strongly need

7- To what extent you are satisfied from the information on the collections (lables)?

◯ Strongly not satisfied ◯ Not satisfied ◯ Neutral ◯ Satisfied ◯ Strongly Satisfied

8- Have you read most of the text in the labels next to the collection?

◯ No ◯ few of them ◯ average ◯ Most of it ◯ Yes

9- To what extent you feel you need more supplementary visual information (e.g. images, audio, videos) aside with text on labels?

◯ Strongly don't need ◯ Don't need ◯ Neutral ◯ I need ◯ Strongly need

10- To what extent you feel interested to do your touring without guidance method?

◯ Bored ◯ Not interested ◯ Neutral ◯ Interested ◯ Very Interested

11- To what extent you feel engaged with the museum context?

◯ Strongly disengaged ◯ Not engaged ◯ Neutral ◯ engaged ◯ Very engaged

(If it is Yes please answer the next questions)

6- To what extent you feel you are independent in the group tour following the guide

◯ Very dependent ◯ dependent ◯ Neutral ◯ independent ◯ Very independent

7- Did you acquire all information you need from the visit? ◯ Yes ◯ May be ◯ No

1

8- To what extent you feel you want more supplementary visual information (e.g. images, videos) aside the guide narration ◯ Yes ◯ May be ◯ No

9- Could you hear most of the explanation demonstrated by the tour guide?

◯ No ◯ few of them ◯ avarage ◯ most of it ◯ Yes

10- If you miss part of the explainations, would you stop the tour guide and ask him/her for repeat ? ◯ No ◯ few times ◯ avarage ◯ most of the time ◯ Yes every time

11- To what extent you agree with this statement "The atmosphere of the museum is too noisy to hear what the tour guide is saying"?

◯ Strongly disagree ◯ Disagree ◯ Neutral ◯ Agree ◯ Strongly agree

Section 3# Augmented/ Mixed Reality Awareness

12- Are you aware of the term "Augmented Reality" or "Mixed Reality? ◯ Yes ◯ No

13- Have you ever worn headsets for Virtual Reality or Mixed Reality before? ◯ Yes ◯ No

if yes, please mention the headset ....

14- Have you heard about any of these Augmented Reality applications such as "Layar, Wikitude, VouchAR, AR Commando or Pokémon Go"? ◯ Yes ◯ No

15- Have you ever experienced Augmented Reality applications? ◯ Yes ◯ No

16- Have you experienced "AR" apps in museums before? ◯ Yes ◯ No

MUSEUMEYE SURVEY- AFTERTOURING

SECTION 1# CONTENT

1. The storytelling of King Tutankhamun is interesting.

Strongly Disagree	Disagree	Neither	Agree	Strongly Agree
1	2	3	4	5

2. The language is clear and understandable.

Strongly Disagree	Disagree	Neither	Agree	Strongly Agree
1	2	3	4	5

3. Images signposted during the narration are interesting and beneficial.

Strongly Disagree	Disagree	Neither	Agree	Strongly Agree
1	2	3	4	5

4. The information about the collection is enough and covers most of what you expect.

Strongly Disagree	Disagree	Neither	Agree	Strongly Agree
1	2	3	4	5

5. I could clearly see the benefit of exploring (by spinning) the virtual antiques.

Strongly Disagree	Disagree	Neither	Agree	Strongly Agree
1	2	3	4	5

6. Revealing the secret information around the antiques is interesting.

Strongly Disagree	Disagree	Neither	Agree	Strongly Agree
1	2	3	4	5

7. The content of MuseumEye is engaging and makes me focus to the explanation till the end.

Strongly Disagree	Disagree	Neither	Agree	Strongly Agree
1	2	3	4	5

SECTION 2# MULTIMEDIA DESIGN

8. I like the 3D characters (king, queen, maids ..etc).

Strongly Disagree	Disagree	Neither	Agree	Strongly Agree
1	2	3	4	5

9. The historical music is engaging and helps to immerse myself in the virtual environment.

Strongly Disagree	Disagree	Neither	Agree	Strongly Agree
1	2	3	4	5

10. The 3D scanned antiques (virtual replica) is representing the authentic pieces.

Strongly Disagree	Disagree	Neither	Agree	Strongly Agree
1	2	3	4	5

11. I like the user interface design (buttons, graphics, icons ... etc).

Strongly Disagree	Disagree	Neither	Agree	Strongly Agree
1	2	3	4	5

SECTION 3# USABILITY AND INTERACTIVITY

12. It was comfortable to use the 'MuseumEye' application.

Strongly Disagree	Disagree	Neither	Agree	Strongly Agree
1	2	3	4	5

13. I did not experience nausea, dizziness, or headache using the 'MuseumEye' application

Strongly Disagree	Disagree	Neither	Agree	Strongly Agree
1	2	3	4	5

14. I could look around the room comfortably, without any discomfort

Strongly Disagree	Disagree	Neither	Agree	Strongly Agree
1	2	3	4	5

15. I could do air tap on the virtual objects appropriately (hand gesture).

Strongly Disagree	Disagree	Neither	Agree	Strongly Agree
1	2	3	4	5

16. I could interact with the user interface as I expected.

Strongly Disagree	Disagree	Neither	Agree	Strongly Agree
1	2	3	4	5

17. I could move between scenes easily.

Strongly Disagree	Disagree	Neither	Agree	Strongly Agree
1	2	3	4	5

18. I could reveal all hints (information) from yellow circles easily .

Strongly Disagree	Disagree	Neither	Agree	Strongly Agree
1	2	3	4	5

SECTION 4# MUSEUMEYE AS A ROLE OF GUIDANCE

19. I found this application interesting.

Strongly Disagree	Disagree	Neither	Agree	Strongly Agree
1	2	3	4	5

20. I found this application is useful for guidance.

Strongly Disagree	Disagree	Neither	Agree	Strongly Agree
1	2	3	4	5

21. I think using this application, it will enhance the understanding of histroical knowledge.

Strongly Disagree	Disagree	Neither	Agree	Strongly Agree
1	2	3	4	5

22. I think visitors will be more independent in their tours by using this application.

Strongly Disagree	Disagree	Neither	Agree	Strongly Agree
1	2	3	4	5

23. I see this application more like a tour guide than a necessary tool for guidance.

Strongly Disagree	Disagree	Neither	Agree	Strongly Agree
1	2	3	4	5

24. I want to see more storytelling and other contexts developed into MuseumEye.

Strongly Disagree	Disagree	Neither	Agree	Strongly Agree
1	2	3	4	5

SECTION 4# OVERALL SATISFACTION

25. I found this application enjoying.

Strongly Disagree	Disagree	Neither	Agree	Strongly Agree
1	2	3	4	5

26. I became familiar with the application after a short time of using it.

Strongly Disagree	Disagree	Neither	Agree	Strongly Agree
1	2	3	4	5

27. I prefer to use this application as a guiding tool in this museum or other museums as well.

Strongly Disagree	Disagree	Neither	Agree	Strongly Agree
1	2	3	4	5

28. To what extent you can recommend MuseumEye for your friends to use?

Strongly Disagree	Disagree	Neither	Agree	Strongly Agree
1	2	3	4	5

29. What are the best aspects and the other aspects which are you prefered in MuseumEye?

30. What are the aspects and the other aspects which are not so good about MuseumEye?

Thanks for your participation, your participation are very valuable to our research

Appendix E. Budget Estimation for MuseumEye

The following table (Table C and D) demonstrates the cost estimation of applying MuseumEye to cover a range of 100 antiques in a museum including similar storytelling scenes alike MuseumEye. The system can serve 5 visitors simultaneously.

Table C. Costs of the hardware involved to build the guide system

Category	Description	Quantity	Unit Price	Cost
Hardware	3D Scanner 3D Sense	1	$750	$750
	Microsoft HoloLens	5	$3000	$15000
	Facial Capture system -Faceware (indie Ultimate Package) *Not inclusive for this project	1	$4297	$4297
	Motion Capture system – 32 Neuron Edition V2 *Not inclusive for this project	1	$1,799	$1,799
Total				**$21,846**

Table D. Estimated budget for all tasks required to build the guide system

Task	Person who will do this task	Cost/ hour	Estimated Hours	Cost
Creating database on a cloud server and link it to the system	Software developer	$25	$20	$500
Data entry to the database	Data Entry Specialist	$15	30	$450
3D Modeling (Characters + Antiques)	3D Modeler	$20	100	$2000
3D Scanning	3D Modeler	$20	20	$400
Building the virtual scenes and the storytelling scenes	Environment Artist	$30	20	$500
Animating virtual Characters	3D Animator	$35	30	$1050
Museum content creation	Curators and Academic experts	$20	25	$500
Audio Content + Recording narrations	Content Narrator	$10	5	$50
Developing the MR guide system	MR Developer	$30	70	$2100
Creating the UI design	Graphic Designer	$20	20	$400
Creating Multimedia Content	Motion Graphic Designer	$25	100	$2500
Testing the guide system	Developer	$20	5	$100
Total				**$10,550**

The estimated budget including the equipment (hardware and software) required is roughly $21,846 + $10,550 = $32,396.