VIRTUALIZING THE UNCERTAINTY OF DIGITAL ARCHAEOLOGICAL RECONSTRUCTIONS APPLICATION ON THE EGYPTIAN LABYRINTH OF HAWARA

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I. ABSTRACT

The virtual reconstruction of archaeological sites has been a debatable field of research for decades. Archaeology theorists have questioned whether digitization is a reliable tool for visualizing history and presenting it to the public, and the uncertainty associated with digital reconstructions requires further investigation. The aim of this research is to investigate the viability of using virtual reality to represent the uncertainty of digital archaeological reconstructions to a non-specialist audience by developing and testing a virtual reality experience based on a real archaeological site. Drawing on existing literature on virtual reality as a technology, its applications in the reconstruction of archaeological sites, and an examination of the uncertainty of digital reconstructions of archaeological sites, it develops a theoretical framework for representing the uncertainty of archaeological reconstruction using virtual reality models. The framework is then developed and validated through interviews with experts in the field. The applied outcomes of the study are divided into three parts. In the first, the interviews with the experts were analyzed using Nvivo software in order to understand how they perceive and interpret archaeological data and evidence during the reconstruction process. The second outcome was the creation of a virtual reality experience based on historic reconstructions of the ancient Hawara Pyramid and Labyrinth site at Fayoum, Egypt. The virtual reality experience presents three versions of the site, each based on an historic reconstruction by a different ancient historian, namely Kircher, Lucas, and Canina. The aim in presenting these different interpretations together was to test whether the experience could be used to visualize the uncertainty which arises due to conflicting evidence. The third outcome involved testing the experience with members of the general public in order to gather users' feedback regarding the use of virtual reality in the field of archaeology and heritage and its effectiveness in conveying the uncertainty within digital archaeological reconstructions. Data was gathered via a survey of users at different locations in Cairo, Egypt. The main thesis contribution to knowledge is generating a novel approach for representing the uncertainty of digital archaeological reconstructions using a virtual reality experience.The methodology and prototype used can be applied on other archaeological sites leading to a theoretical and practical advancement in this field of research.

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"I dedicate this thesis to my late mother
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1. CHAPTER 1: INTRODUCTION

1.1 Research Background

The reconstruction of archaeological sites has taken different forms throughout history. The very earliest reconstructions, or rather descriptions, of archaeological sites were in the form of text and manuscripts, and these were followed by visual reconstructions, which were introduced during medieval times. These early visual descriptions were based on accounts of past travellers or religious books, such as the Bible. However, with the introduction of archaeology as a science in the 19th century, archaeological reconstructions started to be based on actual material evidence, and this affected the reliability of the earlier archaeological reconstructions which were then considered to be largely hypothetical due to the lack of comparable data. By the end of the 19th century, archaeological reconstructions had become much less hypothetical as archaeological evidence was becoming much more available to refer to for comparative study. Following on from two dimensional reconstructions, the rise of three-dimensional reconstructions has now made it possible not only to view reconstructions but also to experience them in the form of virtual simulations (Hageneuer, 2015).

However, virtual reconstructions have always been a debatable field of research for archaeologists. (P. Reilly, 1991)This is due to two main reasons: firstly, the fact that virtual reality might present one interpretation of the reconstruction of an archaeological site as a definite reality without the possibility of also presenting other interpretations; Secondly, the fact that virtual reconstructions of the past could act as a "black box", meaning that the evidence used for the reconstruction, as well as the interpretation process, might become unclear to the users and experts when exploring the virtual reconstruction (Demetrescu & Ferdani, 2021). In this context, virtual archaeology could be understood as an illusion, a replica, or an approach to create a copy of an original; this means it is considered as a description of an archaeological *interpretation* in the form of a visual presentation. The issue then relates to the transparency of the components that form the interpretation of the archaeological data under study, without which it will not be clear to the user what types of evidence were used or what kind of methodology was adopted to interpret the data and to reach this reconstruction. This includes transparency in both data handling and the interpretation of data (Reilly, 1991).

Despite criticisms of the use of virtual reality in the field of archaeological reconstructions, it has been agreed that there are multiple benefits of virtual reconstructions, not only as a visual representation of the past but also in furthering cognitive understanding of complex information and data related to archaeological sites and how they may have looked like in the past.(Addison, 2000)(Barcelo et al., 2000) (Forte and Siliotti, 1997)3D simulations are believed to make it easier to manage and understand complex data related to archaeological sites (Demetrescu & Ferdani, 2021). However, the use of this technology in the field of archaeology and heritage is still relatively new, and its capabilities in this context remain under-explored in the literature.

1.2 Research Problem

As previously mentioned, virtual reality now makes it possible to represent archaeological sites through virtual worlds that are independent of actuality. This raises the issue of the uncertainty of digital archaeological reconstructions. The previous media used for representing archaeological reconstruction, such as two-dimensional drawings, did not have the same realistic effects as three dimensional reconstructions, especially as virtual reality headsets now enable users to become totally immersed in the reconstruction. This is the main reason why archaeology theorists have criticised the use of virtual reality in reconstructing archaeological sites, citing concerns that such technologies represent the past as a fixed known reality.(Cameron, 2007)

On the other hand, virtual reality as a technology has the capacity to provide further data about archaeological sites, and it can also be used to present multiple interpretations of the same site. As such, it constitutes an important archaeological tool. However, there is currently little research addressing the issue of uncertainty in digital archaeological reconstructions and how this might be addressed. This study contributes to knowledge by exploring the application of virtual reality in the context of ancient Egyptian archaeology, specifically in relation to the Hawara labyrinth and pyramid, and developing theoretical and methodological frameworks to represent the uncertainty of archaeological reconstructions in virtual reality models.

1.3 Research Aim and Objectives

The main aim of this research is to explore the application of advanced virtual reality to understand ancient architectural and archaeological history through the representation and reconstruction of the multiple interpretations of the Hawara pyramid site in Fayoum, Egypt.

In order to achieve this aim, the following objectives have been established:

- Exploring the possibility of representing different interpretations of history through the virtual reconstruction of historical and archaeological sites;
- Differentiating between the evidence-based data and the speculative data used in the interpretation of the historical and archaeological sites;
- Identifying the degree of subjectivity of the different types of evidence used in the interpretation of historical or archaeological sites and categorising them from the least subjective to the most subjective;
- Developing a theoretical framework for the uncertainty of archaeological reconstructions;
- Developing a methodological framework for representing the uncertainty of archaeological reconstructions in virtual reality models based on a review of the literature and experts' validation;
- Testing the methodological framework for representing the uncertainty of archaeological reconstructions by applying it to the Hawara labyrinth and pyramid as a case study.

1.4 Research Questions

In achieving the objectives set out above, the study aims to answer the following research questions:

1) How can virtual reality act as a media for visualizing the uncertainty of digital archaeological reconstructions?
2) What are the factors contributing to the subjectivity and uncertainty of digital archaeological reconstructions?
3) Is virtual reality a suitable media for presenting to the general public the uncertainty of digital archaeological reconstructions?

1.5 Thesis Structure

The thesis is divided into nine chapters, including this introductory chapter. The second and third chapters cover the literature review and determine the research focus and scope in relation to the existing literature. Chapter Two, entitled "Digital Archaeology and Integrated Modelling" includes an introduction to the field of digital archaeology, in both its theoretical and methodological applications. The first section covers the theoretical underpinning of digital archaeology in relation to current archaeological theories and discusses different reflections on this relatively new field of research in order to provide a better understanding of the scope of this field, which is still under exploration. As the focus of this research is on using virtual reality in the field of archaeological reconstructions, the second part of the chapter examines virtual archaeology, which is considered a sub discipline within digital archaeology. Virtual archaeology and its different applications are explored, with example different types of projects which have utilised virtual archaeology, in order to determine the scope of the current research, its philosophical position, and the methodological approach adopted. A study of the different technologies used in both the documentation of existing remains and the generation of integrated virtual models is provided at the end of the chapter. These different methods are then incorporated within the theoretical framework in the following chapter.

Chapter Three, entitled “Theorizing the Uncertainty of Virtual Archaeological Reconstructions”, aims to theorize the uncertainty of digital archaeological reconstructions within virtual reality environments. The chapter begins by discussing uncertainty as a general theoretical concept and provides a classification of uncertainty in scientific research, followed by several definitions of uncertainty. These two sections form the theoretical basis for the rest of the chapter. This is then followed by discussing the uncertainty of digital archaeological reconstructions leading to multi-interpretations, including the sources of data, the types of data, and the characteristics of data and visualization of data. This leads to a classification of the factors contributing to the uncertainty associated with digital reconstructions. The subsequent sections include a list of all the charters and principles that discuss guidelines to be followed in order to eliminate or diminish the uncertainty involved. The most important and recent research work in the field is then discussed in order to define a gap in the existing body of knowledge.

The final outcomes of this chapter are:

1- The classification of the factors contributing to the uncertainty in digital archaeological reconstructions.
2- The development of a theoretical framework addressing the representation of uncertainty within virtual reality environments, including modelling, interaction and immersion.

Chapter Four, “Research Methodology”, explains the research methodology used within the research. This includes the methodological approach adopted and the data gathering and data analysis techniques used. The methodology used for the interviews with experts, the development of the virtual reality experience, as well as the users' feedback regarding the experience is also discussed.

The second phase is dedicated to the validation of the theoretical framework. This phase includes one chapter, Chapter Five, entitled “Experts’ Validation of the Subjective Uncertainty of Digital

Archaeological Reconstructions", which examines the subjective uncertainty in digital archaeological reconstructions and covers the use of digital archaeology as a media for representing the uncertainty within these reconstructions. It also explores the various factors that lead to differences in interpretations by experts in order to generate digital reconstructions. This will be achieved through exploring the following; Is it valid to question archaeological interpretations? To what extent are archaeological interpretations subjective? How much does the experts' background and knowledge impact the degree of uncertainty? How could subjective uncertainty be represented in archaeological reconstructions? Does virtual reality offer new possibilities for representing subjective uncertainty in archaeological reconstructions? In order to address these points an interview is conducted with several experts in the field of cultural heritage and archaeological reconstructions. The experts will be from various socio cultural and educational backgrounds. The limitation would be to choose experts who were previously involved in archaeological interpretations and reconstruction of heritage sites.

The data gathering is conducted through one-to-one interview. One to one interview is selected as a data gathering method in opposition to surveys as the aim to study the subjectivity of archaeological interpretations. One to one interviews are considered more suitable for qualitative research that target certain participants with the aim of understanding their motivation into taking certain decisions. As the aim of this interview to explore how experts interpret archaeological data and how this results in subjective uncertainty, one to one interviews are used.

The third phase involves applying the chosen methodology to the theoretical findings from the case study of the Hawara pyramid site in Fayoum in order to assess and evaluate the feasibility of the theoretical framework. The methodological approach focuses on representing subjective uncertainty by using virtual reality technologies to create a 4D diachronic prototype model to represent several interpretations of the same archaeological site. This involves the use of the interactivity aspect within virtual reality to present the subjectivity of archaeological reconstructions and interpretations. The focus on representing the subjectivity of experts' interpretation to the public is a novel approach. This phase includes three chapters, Chapter 6, 7, and 8.

Chapter Six, entitled "The Labyrinth of Hawara in Between Virtuality and Reality: Tracing the Virtual Reconstruction of the Labyrinth of Egypt Along History", reports the first part of the case study research which involved a historical and archaeological study of the site. This included gathering all the resources available relating to the site at Fayoum and generating two sets of data: one which includes previous reconstructions of the site and the other which comprises real archaeological evidence, as well as other supporting evidence.

Chapter Seven, "Virtualizing the Uncertainty Of Digital Archaeological Reconstructions" includes the process for developing a virtual reality experience to present several interpretations of the Labyrinth of Egypt in order to investigate the possibility of using virtual reality to display the uncertainty of digital archaeological reconstructions. Previous attempts at reconstructing the site are visualized using integrated modelling in order to present various interpretations of the same site through history; using virtual reality in this way will allow the user to understand the subjective nature of archaeological interpretations. Modelling of each interpretation of the site is created using SketchUp, and these models are then integrated using Unity 3D software.

The different interpretations are converted into a multiple scene virtual reality experience, again using Unity 3D. Modelling of the currently existing remains is generated by photogrammetry modelling using Agisoft software in order to study the possibility of integrating real fragments from the site into the virtual reality experience. The development of a virtual reality experience is created in order to highlight the concept of subjective uncertainty and to demonstrate to the user that, even with the use of the latest technologies available to us, any attempted archaeological reconstruction is still subjective. The final model is based on post processual archaeology theories and forms an interactive model that includes archaeological remains from the site. The user is able to interact with the model in order to access further details about the archaeological fragments.

Chapter Eight, "Exploring and Evaluating the Uncertainty of Digital Archaeological Reconstructions Through Virtual Reality" includes users' feedback regarding the virtual reality experience developed in the previous chapter. A sample of fifty participants from different backgrounds tested the virtual reality experience and were then invited to participate in a survey to give their opinion regarding the experience. There was no specific selection criteria for the users as the experience is targeting the general public. The chapter includes analysis of the users' feedback and suggestions as well as the researcher's comments regarding the observations made while testing the virtual reality experience.

Chapter Nine "Discussion and Conclusion" is the final chapter of this thesis. It covers a summary of the research main findings. This chapter explore how all the research questions were addressed in the research sections. The discussion chapter also covers the research findings in relation to existing literature. The chapter covers the strengths and limitations of using virtual reality in representing the uncertainty of digital archaeological reconstructions. The chapter ends with recommendations and insights on future research.

2. CHAPTER 2. DIGITAL ARCHAEOLOGY AND INTEGRATED MODELLING

2.1 Introduction

This chapter provides an introduction to the field of digital archaeology, in both its theoretical and methodological applications. The digital revolution in which archaeology participates has several aspects which impact the present paradigm in the field. Firstly, digital technologies make it possible to represent an abstraction of the real world - whether physical, textual, sound or image - in one compact platform. Secondly, digital technologies have expanded quantitative methods, such as counting, statistics, and manipulating and evaluating measurements while producing various analytical forms. Thirdly, digital technologies offer the possibility of generating models and simulations of real world processes in order to comprehend the complex interaction processes of humans in their environments. Fourthly, they make possible the creation of virtual worlds that are independent of actuality. Fifthly, digital technologies allow one to transmit all of these manipulations, representations, and words at almost the speed of light to an increasingly global audience (Zubrow, 2006).

The first section covers the theoretical underpinning of digital archaeology in relation to current archaeological theories and discusses different reflections on this relatively new field of research in order to provide a better understanding of its scope, which is still under exploration. As the focus of this research is on using virtual reality in the field of archaeological reconstructions, the second part of the chapter examines virtual archaeology, which is considered as a sub discipline within digital archaeology. Virtual archaeology and its different applications are explored, including different types of projects, in order to determine the scope of the current research, its philosophical position, and the methodological approach adopted. A study of the different technologies used in both the documentation of existing remains and the generation of integrated virtual models is provided at the end of the chapter. These different methods are then incorporated within the theoretical framework in the following chapter.

2.2 Digital Archaeology

Digital archaeology is a scientific field which links archaeology with information and communication technology (ICT), and investigates how innovations in digital technology impact the performance of basic archaeological tools. The main purpose of this research field is to focus upon how ICT and other digital techniques are integrated into archaeological theory and practice in ways that expand the limits of what is possible within archaeology (Daly & Evans, 2006). Digital archaeology has made it possible to document archaeological sites in much greater detail, and digital archiving is now considered as one of the key preventive conservation measures that should be taken at any historic site. Digital technologies also offer the possibility of generating and adding further information on historic sites, including creating 3D models and textual and visual information. This offers endless applications in the field of archaeology, and this chapter explores the ways in which digital technologies have been experimented with and applied on different levels in archaeological projects around the world.

It is important first to explore the theoretical background of the field of digital archaeology. One of the most important books that discuss the theoretical basis for digital archaeology is *Digital Archaeology a Historical Context* by Zubrow (2006). Zubrow explains that archaeology has always been a science that is both concerned with the storied behind the archaeological remains. In this sense, archaeologists and archaeology could be seen as a mixture of scientists and science and storytellers and narrative reconstruction. However, it is a difficult task for archaeologists to derive stories and narratives about humans from the fragmentary remains that have survived the passage of time. People in narratives play an important and active role in the interpretation of archaeology, and they empower the culture and give deeper meanings to the objects. However, they might do so falsely as they are driven by love, fear, and desire, rather than numerical and digital data, and there is always the aspect of uncertainty. By contrast, numerical and digital worlds rarely cause change as they tend to be static and rigid with fixed outcomes. So, stories told in everyday life about the past often coexist uncomfortably with the digital world of measurement, computers, and the statistics of prehistoric material cultures, and there are other disjunctions between narratives and digital archaeology (Zubrow, 2006a). This duality between archaeology and technology is considered as a major paradigm shift in the field of archaeology; however, it is not yet clear if this shift is just a change of tools within the same theoretical thinking or if it will have a greater impact on the theory of archaeology itself.(Daly and Evans, 2006)

The tension between scientific determinism and human interpretation can be seen in the archaeological schools which have influenced digital archaeology and the theories which overlap with it. Processual archaeology (Processualism) or ‘new archaeology’, first introduced by Lewis and Sally Binford in the 1960s, focused on studying archaeology in a scientific manner and considered culture as a set of behavioural processes (Binford & Binford, 1968). Processual archaeologists were influenced by other scientific disciplines and followed scientific methods and testing against evidence. Although processual archaeology is now largely outdated, it still has some influence on digital archaeology. Another archaeological influence is post processual archaeology. This archaeological school was created in the 1980s by Hodder, Shanks, Tilley and Miller as a counter reaction to processualism (Hodder & Hutson, 1986). Ian Hodder was the first archaeology theorist to reflect social action theory in the field of archaeology and made several attempts to create a correlation between them, generating a number of theories which became known as 'post processual archaeology' (Hodder, 1985a). Post processual archaeology is characterised as neo-Marxist, hermeneutic, critical and poststructuralist, and it builds on the social action theory in sociology (Tuomela, 2012) by focusing on how material culture is meaningfully and actively produced.(Preucel, 1995) This means that when studying artefacts, the individual maker, user, actor, history and culture of each object is taken into consideration. In that sense, social action theorists move beyond considering humanity to be passive. (Tuomela, 2012)The difference between processual and post processual archaeology is that processual archaeology is driven by scientific determinism, while post processual archaeologists see this approach as limited and they take into consideration other factors that influence the interpretation of archaeological artefacts, such as uncertainty and unpredictability of human behaviour. They also recognise the subjectivity of the interpretations while considering individual and collective contributions. (Hodder, 2014)

The digitization and information processing approaches in archaeology are often criticized by post processual archaeology theorists such as Hodder for reducing the meanings of the objects involved. Material culture carries meaning whether we deal with it as a tool or as a piece of information (Hodder, 1992a), and, in many cases, digitization involves an incompleteness of information. Historian Graeme Davidson argues that a digital copy of material culture is inferior to its non-digital orginal. (Graeme Davison and Bennett, 2003) However, the study of archaeology is always characterized by a sense of uncertainty and incompleteness, and this is the case whether we use digitization as a method or not. (Sorenson, 2016)Although digitization might contribute to the incompleteness of archaeological information, it can also act as a media for combining scattered information into one platform, which, in turn, contributes to a better understanding of its meaning.

2.3 Multiple Reflections on Digital Archaeology: (Epochs and Mythos)

There are two different and opposing views of digital archaeology. One is that digital archaeological developments are mainly methodological; they provide us with new tools, just as any other archaeological tool kits that offer solutions for archaeological problems created by different theoretical and narrative concerns do.(Daly and Evans, 2006) From this viewpoint, digital archaeology is seen as just other archaeological tool used for dating archaeological remains or environmental reconstruction techniques, such as radio carbon dating or palynology. Many theorists would see these technological tools as being "a-theoretical" or even "anti-theoretical" on the basis that these techniques are universal and could be used in any theoretical approach.(Brey and Søraker, 2009) In their view, digital technologies have an impact on the field of archaeology just as other dating technologies do, and they can be used by cultural historians, 'processual', 'post processual', or even 'post-post processual' archaeologists, as they are not linked to any particular theoretical approaches. They might just need to be adjusted slightly for certain theoretical viewpoints to ensure they are not affected by specific 'theoretical biases'. If this is done, the application of digital techniques is the same and will produce similar results, regardless of the researchers' viewpoint. (Zubrow, 2006)

The opposing view is that digital technologies generate, or at least influence the generation of, new theories, based on the belief that digital developments determine the scope of archaeological theory in many ways. For instance, digital platforms make it possible to emphasize both the very large and the very small, and this creates the possibility of focusing on the individual as an active participant. There is ongoing debate about whether digital technologies are simply tools to explore archaeological data or something more than that. Some theorists consider digital technologies as platforms that provide us with new realities, giving digital archaeology a much deeper dimension than being a mere tool. Indeed, Zubrow (2006) posits that, if digital technology reached the level of being able to reconstruct human mental processes, it may actually become a proxy for theory itself.

2.3.1 Digital Archaeology as an Epoch

Epochs are always defined by the most recent technological developments attained at the time. Archaeologists define prehistory as the record of humanity's tools and technologies, and this could be applied to all ages, from the Palaeolithic age, the Mesolithic, the Neolithic, Mumford's Eotechic, Palaeotechnic, and Neotechnic periods,(The Editors of Encyclopaedia Britannica, 2008) or, finally, Orality, (Ong Hartley, John., 2013) Chirographic, Typographic, and Electronic ages.(Staples, 2000) Both the tools, used as well as the makers of these tools, form an important part of any epoch, and they are considered as an important resource to understand more about history. A social construction of digital technologies based upon epochs typically describes the digital revolution as another step in technological advancement in human history. All tools throughout history have been used to conquer nature in some way, and technology is no different. It too is a tool used to control nature, but archaeologists also use technology to study and control the past (Zubrow, 2006, p.11).

2.3.2 Digital Archaeology as a Mythos

Digital technologies should not be seen as just another step along history's path, but as something which could be much more meaningful - a media for creating new worlds, providing 'new utopias' to those who believe them. (Besnier, 2013) New technologies have always promised to provide things that the past failed to provide, and the factory system, automobiles, television, and nuclear energy have all previously given hopes for glorious ages to come. New technology not only overthrows the old ways of doing thing – it brings transformation into a new environment. Digital archaeology is no different, it also generates new worlds. Thus, digital archaeology and the use of technology is not only related to methodology; it also plays a significant role in determining some aspects of theory. (Zubrow, 2006) For some archaeologists, it has become a form of 'technological determinism', meaning that digital technologies determine the development of the society's social structure and cultural values, and that technology is, therefore, becoming a belief system in the digital age.(Averett et al., 2016)

2.4 Challenges of Digital Archaeology

Digital archaeology, by its nature, must grow out of the increasing use of digital technology (Zubrow, 2006, p.12). Although digital technologies offer a lot to many fields, they have some drawbacks when applied in the field of archaeology. The first challenge is represented by the lack of proximity, distance, and identity, and the fact that the disengagement of archaeologists with the sites and artefacts has become less important due to the use of these technologies. The second challenge is that, although digital developments offer many possibilities, they negatively affect the aspect of identity due to this separation.

The third challenge is the fact that the digital age has brought different specialists into the field of archaeology, such as geologists, palynologists, geographers, and economists, as well as enabling the general public to play a more active role in the interpretation of archaeology. While this multidisciplinary approach provides further data which should assist in better interpretation of archaeological remains, there are constant concerns that the boundaries between professional archaeologists, amateur archaeologists, other professionals, and the public is becoming unclear and, in some cases, may even disappear. Some archaeologists even fear this kind of integration of the general public, as certain information, such as the location of archaeological sites, and artefacts needs to be protected in the digital world (Zubrow, 2006, p.11)

The fourth challenge and a key limitation of digital archaeology is represented in the data size required. The data issue arises as a result of the fact that urgent digital analysis and representation conducted without sufficient data negatively affects the results achieved. As the need for archaeologists to be more accurate and sophisticated in their interpretations increases, the amount of data needed to achieve the required accuracy levels increases significantly.

The fifth challenge is the complexity of digital archaeology itself; this could be divided into two sub-challenges. Firstly, although digital archaeology provides a single platform for integrating numerous types of data while reducing errors, this integration creates a high degree of complexity. The use of multiple components in the digital platforms, such as numbers, texts, graphics, sound, and multimedia, along with 3D models, creates a high degree of complexity leading to numerous issues and problems. For example, the use of different components increases the chances of errors, either within each individual component or in the interaction between components. This kind of complexity requires an interdisciplinary approach in archaeology, involving various fields to assist with the interpretation of the past remains. The advancement and the complexity in the field also means there is a need for specialized digital archaeologists. Secondly, the complexity of the data and the use of advanced technologies, as well as the advanced methodologies and complicated analysis, makes it very difficult for archaeologists to determine the cause and effect of the interpretations.(Daly and Evans, 2006)

The sixth challenge is the 'digital toys' problem. There is a tendency to deal with digital technological solutions just because they are novel, available, and enjoyable to use, and this risks transforming them from scientific tools into being a tool for giving pleasure. Investigating archaeological sites using digital technology becomes enjoyable, just as there is pleasure in fieldwork and in handling artefacts. Archaeologists then become not only field-focused, adventure-focused, and travel-focused, but also technology-focused, rather than primarily people and identity focused (Zubrow, 2006, p.22).

2.5 Virtual Archaeology

Virtual archaeology is concerned with the use of virtual reality technologies in the field of archaeology. It is one application of digital archaeology, and it focuses on converting digital models of archaeological sites into virtual reality experiences. Due to the increase in the different types of data involved in the field of digital archaeology, it is becoming essential to use technologies for generating integrated models that could be used to propose solutions for the better preservation of heritage. As a result, virtual archaeology has expanded from mere 3D visualization to incorporate further data and information. Virtual reality also creates the opportunity of visiting and experiencing archaeological sites with a very close simulation of their previous existence (Refaat & Nofal, 2013).

According to the Seville Charter, an international agreement which sets out the fundamental principles of virtual archaeology, virtual archaeology could be defined as "the scientific discipline that seeks to research and develop ways of using computer-based visualization for the comprehensive management of archaeological heritage" (The Seville Charter, 2011). This field of study extends conventional approaches to the conservation of historic sites, adding a new digital dimension to existing approaches. The integration between these fields means that the outcome of researching and studying virtual archaeology is a type of heritage which is virtual in the sense that it is only existent in digital form and cannot be physically manifest. However, not all reconstruction models of archaeological or historic sites are generated for the same purpose, and several types of virtual archaeology (heritage) models are created for the purpose of recreating part of reality that have been lost over time.

This integration of the virtual environment and cultural heritage is sometimes referred to as "Virtual Heritage". Jacobsen and Holden (2007, p.1)describe virtual heritage as "the use of electronic media to recreate or interpret culture and cultural artifacts as they are today or as they might have been in the past." In addition, Stone and Ojika (2000, p.1) define it as "the use of computer-based interactive technologies to record, preserve, or recreate artifacts and sites of historic, artistic, religious and cultural significance, and to deliver the results openly to global audience in such a way as to provide a formative educational experience through electronic manipulations of time and space." Aydin discusses the difference and similarities between "Virtual Heritage" and "Virtual Archaeology", and claims that the main difference is that virtual heritage mainly focuses on architectural reconstructions, while virtual archaeology is used when the project includes the reconstruction of archaeological ecosystems (Aydin, 2012). However, Reilly (1991, p.133) defines virtual archaeology as "the key concept is *virtual*, an illusion to a model, a replica, the notion that something can act as a surrogate or replacement for an original. In other words , it refers to a description of an archaeological formation or to simulated archaeological formation.". These various definitions indicate that the term "virtual archaeology" is used in many cases that are focused on archaeological or architectural reconstructions, without necessarily involving ecosystems, while the term "heritage", appears to be a more generic term than "archaeology", as it involves current or past heritage as well as tangible and intangible heritage. However, the term "archaeology" is clearly focused on past material culture and would normally be used in respect of different attempts to reconstruct the past through the interpretation of material culture. As this research is focused on archaeological study the term "Virtual Archaeology" is used throughout this thesis.

2.6 Applications of Virtual Archaeology

This section discusses the different types of projects that involve the use of virtual and augmented reality in the field of archaeology and cultural heritage and provides some key examples. The following section "Virtual Archaeology Technologies" provides a summary of the technologies and methodologies used in the various applications that are relevant to this research. There are different types of projects that apply the use of 3D computing, including virtual and augmented reality, in the fields of archaeology and cultural heritage, and the latest state of the art regarding those projects is also explained below.

There are several different applications in which virtual reality could contribute to the conservation of historic or archaeological sites, and this section explores the various classifications for the applications of virtual archaeology which have been developed. The first of these is by Addison (2000) and identifies the applications of virtual reality in three different forms a) in 3D documentation of heritage sites, b) in 3D representation of heritage sites through visualization, and c) in 3D dissemination, such as using *in situ* augmented reality (See Figure 2.1). This broad classification covers the three main domains within which all projects involving the use of virtual reality in the field of heritage and archaeology fall. The 3D documentation covers the types of projects that involve using virtual reality technologies in creating databases of the heritage site, as well as using laser scanning and photogrammetry technologies to create a 3D model for existing remains of the heritage sites. 3D representation covers the types of projects that involve the reconstruction of heritage sites or recreating existing remains in a different form through integrating existing remains with reconstructed parts. And the 3D dissemination type projects include projects through which virtual reality as a technology is used to present heritage sites to the public or to professionals and to disseminate the data created to various users.(Rahaman et al., 2010)

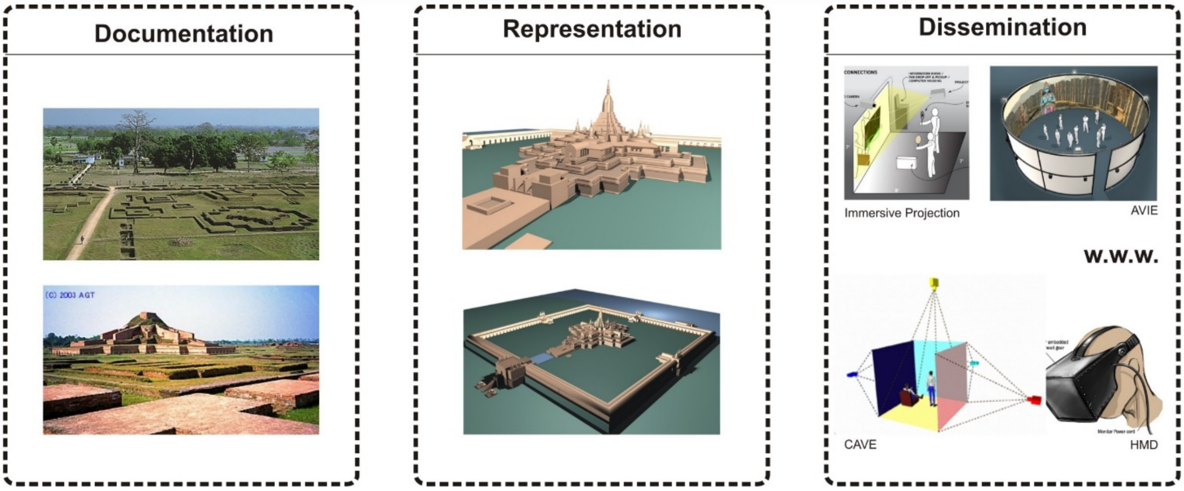


Figure 2.1: Virtual Heritage Project Levels Source: Rahman et al. (2010) p. 1

The second classification was created by Sifniotis (2012) and includes four broad areas: a) preservation and collection; b) site enhancement and promotion; c) education and learning and d) hypotheses and evaluations. This classification, along with that of Addison (2000), covers all the different types of projects, although some projects might cover two types, for example a project could be aiming for 3D documentation and 3D dissemination at the same time. This is explained further by the following examples.

One of the projects that focuses on the preservation and collection or the 3D documentation of heritage sites is CyArk. CyArk is a non-profit organization focusing on using technologies to save cultural heritage. It aims to generate a 3D online library for the world's heritage sites before they are lost to natural disasters, human aggression, or simply due to the passage of time (Kacyra and Kacyra, 2013) One of the projects CyArk is currently working on is located in Ancient Thebes and involves the use of virtual reality for 3D tours inside the site (See Figure 2.2 and Figure 2.3).

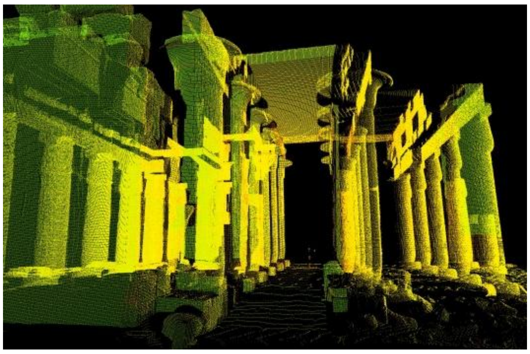


Figure 2.2: Columns in Hypostyle Hall, Ramesseum Main Temple
Source: http://archive.cyark.org/columns-in-hypostyle-hall-ramesseum-main-temple-media

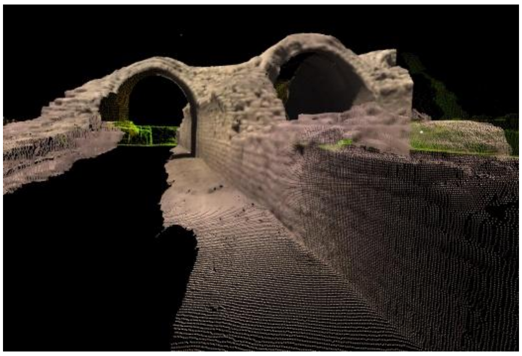


Figure 2.3: Grain Storerooms, Storeroom Precinct of Ramesseum
Source: http://archive.cyark.org/grain-storerooms-storeroom-precinct-of-ramesseum-3-media

An example of site enhancement and promotion through 3D representation is using hand-mounted displays to provide further information about a site by using superimposed reconstructions on top of existing remains, such as those in Archeoguide (Vlahakis et al., 2002) (See Figure 2.4).(Jung et al., 2012) As for education and learning, using 3D models to help in learning environments, either at schools or in the community in general, is widely used in projects. One such example is the Ename 974 project by The Ename Centre for Public Archaeology. The main focus of the project was to disseminate archaeological information to the local and regional community of Ename, which is a rural village situated in the Province of East-Flanders, Belgium (Pletinckx et al., 2000).

Figure 2.4: Archeoguide project which focuses on site enhancement and promotion Source: Jung et al. (2012),p.8

As for the hypotheses and evaluations, few projects currently involve the use of virtual and augmented reality for the sake of exploring archaeological sites and for research. An example of that would be using 3D computing in the representation and analysis of stratigraphic positioning data during an archaeological dig. Stratigraphic positioning data is often very complex and is currently recorded in different formats, such as logbooks and forms; however, the use of 3D computing would allow on site hypotheses testing and analysis of data (Green et al., 2001).

2.7 Virtual Archaeology Technologies

There are different levels in which virtual reality could contribute to the conservation of cultural heritage. Addison, in his research, described these levels in three different forms: firstly in 3D documentation of heritage sites, secondly in 3D representation of heritage sites through visualization, and thirdly in 3D dissemination, such as using *in situ* augmented reality (Addison, 2000). A broad range of technologies are involved, but only the most widely used and successful methods in this research field are discussed here, along with the technologies that are more relevant to the chosen case study.

In order to be able to reconstruct an existing building, a number of different technologies are involved. Some research work involves documentation of existing remains and completing missing parts or sections using 3D modelling programs, while others might involve a fully reconstructed 3D model. The technologies used in the documentation of what originally existed on a site or the remains that have been transferred to another place are explained discussed below; this is followed by a discussion of other technologies used to integrate additional information into created models for further investigation and dissemination of that information.

2.7.1 3D Documentation Technologies

The following sub-sections cover the most recent technologies used for converting material culture into 3D models that can then be used for either virtual, augmented, or mixed reality experiences. The choice of which technologies to use depends on the scale of the project, the accuracy required, the complexity of the object, the resources available, the limitations of the site, and also the main aims of the project (Historic England, 2018).

2.7.1.1 Laser Scanning

Laser scanning is also known as LiDAR scanning, a term usually used for aerial (airborne) scanning, and occasionally, for terrestrial laser scanning (Historic England, 2018), and generates 3D models with considerable accuracy through the generation of a huge number of 3D points (Shanoer and Abed, 2018). Terrestrial laser scanning (TLS) has been the main method of 3D survey of large and complex archaeological and heritage sites for the last decade, and it involves the use of 3D laser scanners and rays to measure the distance between an object or surface and the scanner (Alshawabkeh et al., 2020). There are two main types of terrestrial lidar scanners: (1) time of flight (TOF) scanners and (2) triangulation scanners. TOF scanners are more suitable for large scale projects while triangulation scanners are better for small objects or small parts of buildings (Shanoer and Abed, 2018). The data required for laser scanning can be collected from a tripod, a vehicle, or from the air using drones, and, recently, some hand-held and backpack systems have become available which can be used while walking around a site (Historic England, 2018). Laser scanning is then used to draw a digital surface of an object, surface, or building by measuring its geometric surface and recreating it. This usually produces surfaces that are not textured as they are created simply by connecting several points together; however, a more refined reconstruction is then achieved through the compilation of each set of points, which can be done through numerous scans depending on the scale of the project (See Figure 2.3). The resulting 3D survey model can then be used in a range of different applications (Alves and Bártolo, 2006).

Figure 2.5: Accurate 3D point clouds with shaded and textured models from LiDAR techniques Source : Amans et al., (2013, p. 3)

Laser scanning is widely used in the documentation of heritage buildings, and it can be employed as a stand-alone method or in combination with other surveying instruments, depending on the needs of the project (Shanoer and Abed, 2018).

The following table (Table 1) includes the different types of laser scanning systems and their usage according to Historic England (Historic England, 2018).

Table 1 :Laser scanning systems and their uses Source: Historic England

Scanning System		Usage	Typical Accuracies (mm)	Typical Range (m)
Triangulation	Rotation stage	Small objects taken to scanner. Replica production	0.05	0.1 – 1
	Arm mounted	Small objects. Lab or field. Replica production	0.05	0.1 – 3
	Tripod mounted	Small objects in the field. Replica production	0.1 – 1	0.1 – 2.5
	Close range handheld	Small objects. Lab. Replica production	0.03 – 1	0.2 – 0.3
	Mobile (handheld, backpack)	Awkward locations eg building interiors, caves	0.03 – 30	0.3 – 20
Pulse (TOF)	Terrestrial	Building exteriors/interiors. Drawings, analysis, 3D models	1 – 6	0.5 – 1000
	Mobile (vehicle)	Streetscapes, highways, railways. Drawings, analysis, 3D models	10 – 50	10 – 200
	UAS	Building roofscapes, archaeological sites. Mapping and 3D models	20 – 200	10 - 125
	Aerial	Large site prospecting and mapping	50 – 300	100 – 3500
Phase	Terrestrial	Building exteriors/interiors. Drawing, analysis, 3D models	2 – 10	1 – 300

Laser scanning provides high degrees of accuracy and it usually applied in large scale documentation of heritage sites; however, despite this, the technology also has some disadvantages. Multiple laser scanning techniques only provide models without textures, as they only document the position of the points on the surface in relation to the location of the laser scanner. In addition, laser scanning is not usually very accurate with smaller objects and can show errors in fine details. (Alshawabkeh et al., 2020), and the costs involved are a significant draw back, along with the enormous amount of time and manual effort required to apply it (Alves and Bártolo, 2006).

2.7.1.2 Photogrammetry

Multi-image photogrammetry also known as Structure from Motion (SFM) is a modelling technology that transfers 2D images into 3D models. This is applicable to surfaces, landscapes, objects and buildings (Green et al., 2014). Photogrammetry is a technology that generates 3D models of buildings through manual processing of digital images (Alves & Bártolo, 2006), and it is unique in providing both geometric and texture data together. It is normally used for smaller scale objects, especially for modelling artefacts where it is important to provide textures and materials, because it is too time consuming to use for documenting streets or larger scale buildings. Photogrammetry is much more accessible than other modelling technologies, and it can be used by non-specialists (Jones & Church, 2020); but, the challenge in photogrammetry is usually in the need for closely-spaced images which becomes difficult in large scale projects (Alshawabkeh et al., 2020).

2.8 Integrated Virtual Models

The documentation and reconstruction of cultural heritage and archaeological sites has been advanced by using integrated models. (Ma Li, 2017)Within integrated modelling, further data about the heritage or archaeological sites is embedded within different digital platforms, which then have a variety of numerous applications (these are explained later in this chapter). The two most important systems that are used for this purpose are Building information modelling (BIM) and Geographic information system (GIS) .(Song et al., 2017)BIM as a system aims to provide digital models of buildings that include both physical and functional information to aid with their construction and the monitoring of these aspects post construction (Wang et al., 2019). In BIM models, information is not only characterised in three dimensions, but 4D, 5D, 6D and 7D dimensions are possible and are defined according to the information data sets they are linked with (Castellano-Román & Pinto-Puerto, 2019) Historic building information modelling (HBIM) is an adapted application of BIM which is widely used to generate databases for heritage assets, as these are beneficial to decision-making regarding the sustainability of historic buildings (Hull & Bryan, 2019). HBIM has contributed greatly to the management and documentation of cultural heritage and is even used to present the actual or reconstructed state of archaeological sites in virtual environments. However, the virtual reconstruction of historic or archaeological sites especially is a very complicated process as these are composed of various complex elements, characteristics, and forms that are not found within BIM libraries. This requires the introduction of different approaches, such as point cloud models and other virtual parametric components, in order to be able to achieve an HBIM model that is close to reality. The most important 3D modellers used for building HBIM models are ArchiCAD, Tekla Structures, Bentley System and Revit Autodesk, and widely used 3D viewers include Tekla BIMsight, Navisworks Freedom, and SketchUp. For the analysis phase, the following analysers are usually used; Ecotect analysis, DAYSIM and Energy Plus (López et al., 2018).

GIS, on the other hand, is a computer-based system that operates through geography, cartography, and remote sensing technology. It is used to collect, store, manage, calculate, analyse, display, and describe spatial information and data about the earth's surface, including buildings (Wang et al., 2019). GIS is typically used in heritage projects to study the influence of geographic data on heritage or archaeological sites. It can be used either for creating models that could be transferred to augmented reality experiences, for example, as it allows the data to be connected to a geographic location. It could also be used to create geo located web repositories for 3D digital heritage sites (Nishanbaev, 2020).

One of the most recent technologies for the smart preservation of cultural heritage is 5D GIS. A 5D GIS model is used to integrate different information about heritage sites. The traditional 2D GIS saves the information for X and Y axis, and the more recent 3D GIS includes third dimensional information, including heights and other data that is used by urban planners for decision making regarding planning. However, the 5D GIS model makes it possible to integrate more information about the site, by adding a fourth and fifth dimension. The fourth dimension includes time and associated collective memories about the place, while the fifth includes automated virtual and augmented heritage which is used to take 360˚ videos and images for the site (Ma Li, 2017).

Research work has been developing to integrate both BIM and GIS within the same project. The diagram below (See Figure 2.6) shows how these systems have developed beyond simple visualization to be used for mathematical modelling and integrating further information into the technology (Song et al., 2017). As the diagram shows, this has allowed the integration of numerous dimensions which are now widely applied in the field of virtual archaeology. The choice of whether to use GIS, BIM or an integration of them both depends on the project's aims and scale.

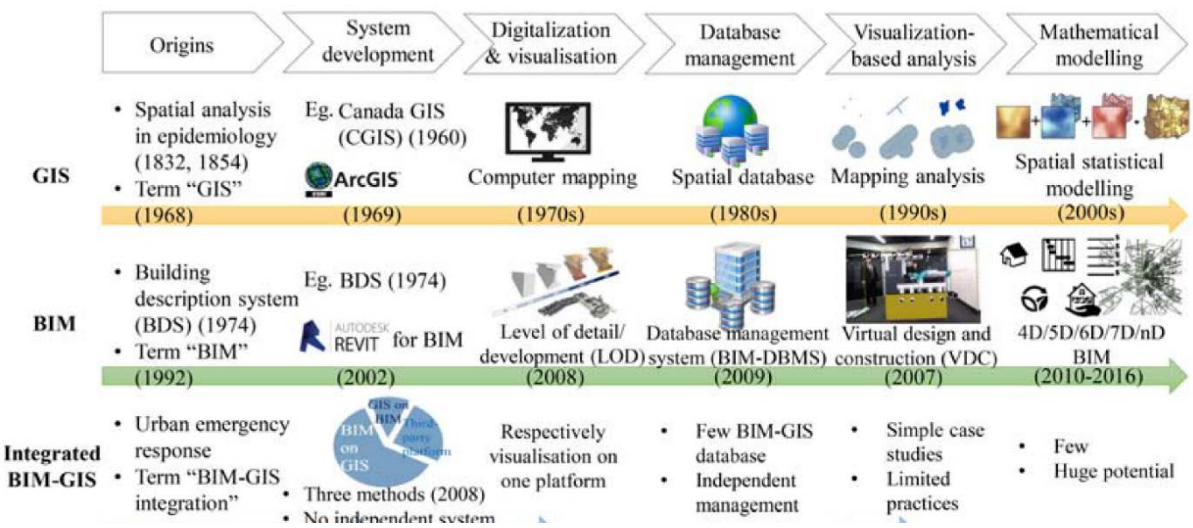


Figure 2.6: The development of using GIS and BIM in visualization and mathematical modelling. Source: http://www.mdpi.com/ijgi/ijgi-06-00397/article_deploy/html/images/ijgi-06-00397-g003.png

2.9 Integrated Models and Virtual Reconstruction

Integrated models are used in order to be able to integrate further information about the reconstructed sites. However, integrated models, especially HBIM, are not solely used for complete buildings. In some cases, they are also used in archaeological projects to reconstruct sections that no longer exist or are at least partially lost. While HBIM is usually used to inform decisions regarding the sustainable preservation of heritage sites that still exist, it is also used to create reconstructed models. These models could then be used in various applications, as the examples below illustrate.

For instance, research work by Angulo et. al. (2017) aimed at generating a virtual *anastylosis* of the old monastery of San Augustin in Seville, Spain. The virtual reconstruction was based on different types of data, including fragments, documents on its construction conditions, archive photographs, and other designs by the same architect. Several technologies were used in the reconstruction attempt, including digital photogrammetry for existing remains as well as reverse engineering, BIM, and visual programming for modelling the lost sections. The final outcome of this research work is an HBIM model of the site. As shown in the figure below (See Figure 2.7) a photogrammetry model was first generated on site. A drone fitted with a camera (DJI Phantom 2 quadcopter with three Zenmuse H3-3D axes and integrated GoPro 3+ camera) was used for the creation of the photogrammetry model. The model was then overlaid on a proposed building elevation based on previous buildings designed by the same architect. This was followed by creating the HBIM model which was generated using Autodesk Revit in collaboration with Autodesk Dynamo which allows the flow of data from the HBIM model to the database(Angulo et al., 2017) (Angulo et al., 2017).

Figure 2.7: Graphical visualisations filtered by theme: a) Anastylosis, b) Sections, c) Weight of pieces. Section with identification of pieces). Source: Angulo et al. (2017)

Research work by Baik (2017), on the other hand, focused on generating an HBIM model for an existing building, a historical Nasif house in Jeddah, Saudi Arabia. The first phase, the 3D survey of the existing building, was generated through laser scanning, using Leica scan-station C10. The scans were then registered in order to generate a complete point cloud model using Lyca cyclone, as shown Figure (2.8) This was then followed by generating a simplified model of the house (See Figure (2.9). Some parts of the point cloud model were then selected to be modelled separately to be included in the HBIM model library and inserted later into the model. Autodesk Revit software was used for the modelling of the house and the separate architectural elements(Baik, 2017) (Baik, 2017).

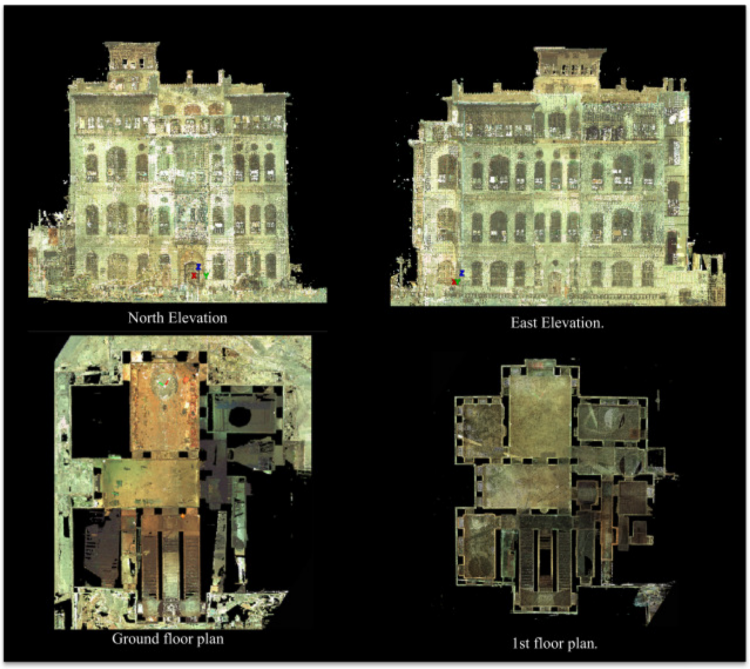


Figure 2.8: The resulting combinations of scans for 3D point cloud model. Source: Baik (2017)

Figure 29.: Images showing the simplified modelling process and finally the textured model. Source: Baik (2017)

Other technologies, such as the Auto-composing virtual heritage system, are more focused on recreating the connection between the community and inaccessible heritage sites. This system allows people to visit a site virtually through the integration of both GIS and multimedia, reducing the threat of causing physical damage to it. The system includes the three different phases shown in Figure 2.10. The first is the digital archiving of the information along with the GIS database; these are then combined through the media congregation phase in different layers, resulting in the final visualization model of the heritage site . (Shih et al., 2006)

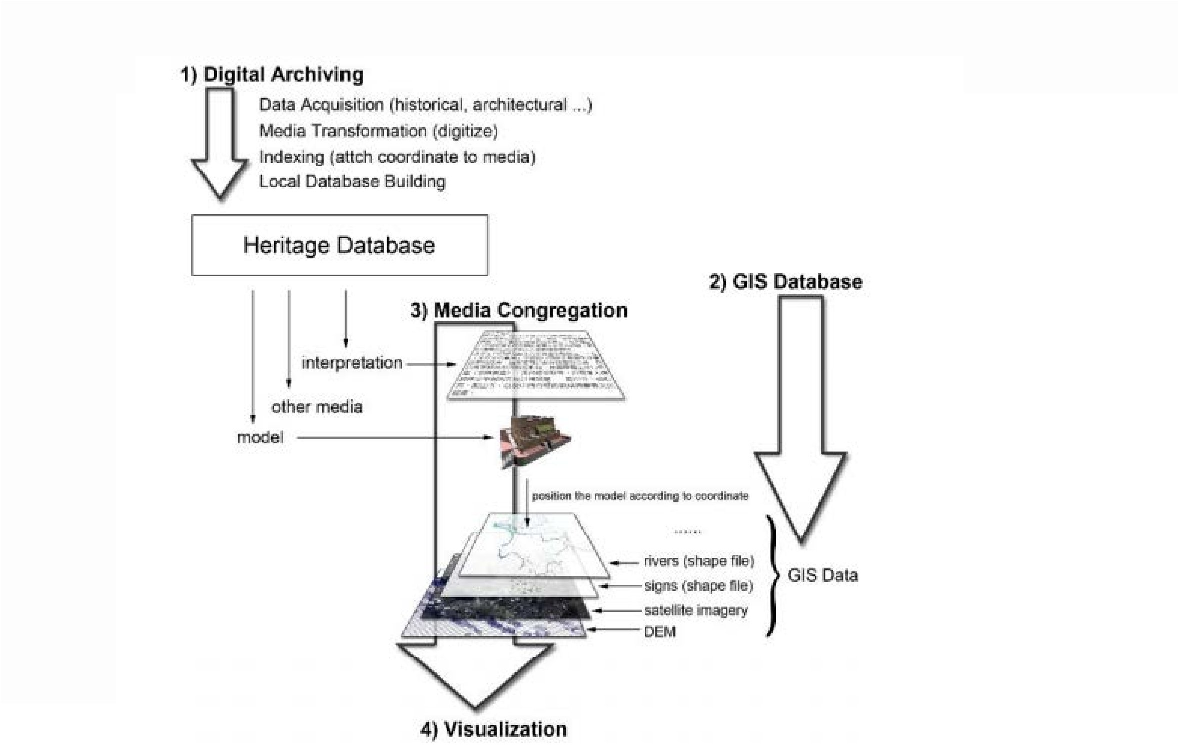


Figure 2.10: Auto composing virtual heritage system
Source: http://papers.cumincad.org/data/works/att/caadria2006_487.content.pdf

One example of including further dimensions in integrated virtual models is 4D diachronic modelling. The 4D diachronic reconstruction is based in principle on 3D surveys of the existing situation of the cultural heritage site and building upon it. A similar reconstruction has been conducted for the medieval wall of Avilla, Spain (Rodríguez-Gonzálvez et al., 2018). Mobile laser systems and various geotechnologies were used in this case study to record the existing condition through a 3D survey. As for the historical resources, the reconstruction was mainly based on ancient drawings, which provided a huge degree of precision. In addition to that historical photographs, maps and testimonies were also gathered. The historical resources were used in order to create a sort of temporal reconstruction of the site, with two 4D diachronic reconstructions of the site existing in two different time intervals (See

Figure 211.). The main contribution of this research work was creating 4D modelling of a heritage site through reverse engineering and the fusion of information (Rodríguez-Gonzálvez et al., 2018).(Rodríguez-Gonzálvez et al., 2017)

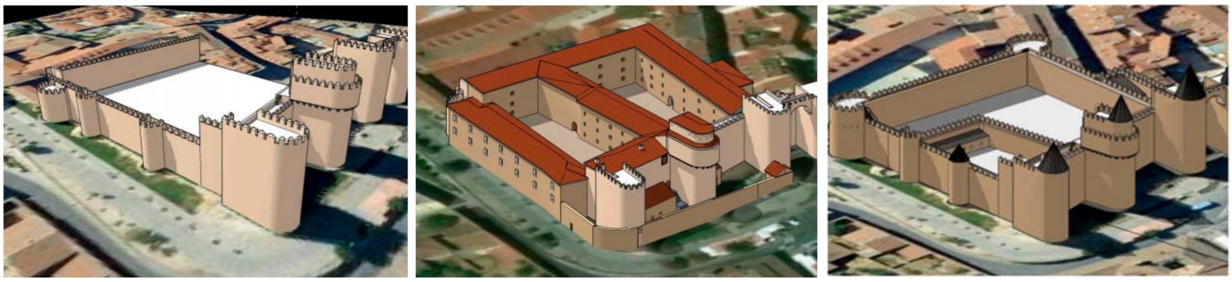


Figure 211.: A 4D diachronic reconstruction for the Citadel of Alcazar in different historic periods Source: Rodriguez-Gonzalvez (2018) p. 10,11,12

2.10 Conclusion

Digital archaeology is considered as a turning point in dealing with archaeological artefacts. (Zubrow, 2006)It not only offers us new tools to discover further data regarding archaeological sites and artefacts, it heralds a new age. It's impact is not only methodological, it is also changing archaeological theory. Digital archaeology interacts with and has empowered archaeological theory.(Daly and Evans, 2006) It has the potential to change our perception, interpretation, and understanding of archaeological artefacts, and it opens up the possibility of creating new worlds based on past objects. Digital archaeology influences and changes the development of visualizations and communications systems and expands the possibilities of extended reality technologies which will enable the use of different types of realities while engaging the public. There should, however, always be a clear separation between the digital worlds which are generated and the real material culture.

Digital technologies provide specialists with advanced methods for data organization and statistics, modelling and simulation, individual visualization and GIS. Digital archaeology also provides different types of spatial, geometric and temporal systems by studying a broad amount of prehistoric problems. However, professionals need to be fully aware of the difference between the real and the semi-virtual worlds these media allow us to create. There is a mythos (strong belief) in the capability and promise of what digital archaeology will offer that needs to be constrained. According to post processual archaeology, computing should just be an additional method and it should only be used during the archaeological process in the field as it has certain limitations. This is due to the fact that digital archaeology lacks the aspect of identity. Post processual archaeology suggests the minimization of digital archaeology and the maximization of public participation in the digitization process.(Hodder, 1985)

Virtual archaeology is one example of the use of digital archaeology in an application that expands the usual understanding of digital archaeology as a mere tool. Virtual archaeology allows the generation of new worlds that will impact archaeological theories. It also has a huge impact on the public's understanding of archaeological sites and their history. Virtual archaeology not only includes the reconstruction of heritage sites and their transfer into virtual environments; it can also include the use of integrated modelling such as BIM and GIS. The choice of which type of modelling to use depends on the project type, with BIM more appropriate for architectural detailing and the integration of structural, mechanical, and electrical systems etc, while GIS is better for integrating contextual data, such as geographic information, environmental influences and geolocation within maps.

3. CHAPTER 3: THEORIZING THE UNCERTAINTY OF VIRTUAL ARCHAEOLOGICAL RECONSTRUCTIONS

3.1 Introduction

"Archaeology has always been concerned both with telling the story of the past and telling stories about the past. […] There is a gap and one frequently find problems associated with the gulf between stories and numbers. […] So in any case, it is not surprising that stories told in everyday life about the past often coexist uncomfortably with the digital world of measurement, computers, and the statistics of prehistoric material cultures." (Zubrow, 2006b)

With the rise in the use of digital technologies in the field of archaeology and cultural heritage, multiple debates have begun to take place. One of the main issues has been around the generation of digitized models of existing or lost archaeological sites (Zubrow, 2006b). With the ease of generating and disseminating such models, digital technologies became a useful tool, and it is tempting to use them to generate unlimited reconstructions for archaeological sites. However, they can also become a threat if misused, and many archaeology theorists have expressed concerns over the use of such technologies in the field of cultural heritage. (Dennis, 2020)Archaeologists have been particularly concerned about the misuse of digital technologies in interpreting history leading to false 3D reconstructions of archaeological sites (Hodder, 1992b). While various media were previously used to virtually reconstruct archaeological sites, either in the form of text or two-dimensional drawings (Stanley-Price, 2009), the use of three dimensionality, as well as fourth and even fifth dimensionality, such as in virtual reality experiences, has raised a new set of issues and concerns. Although there is no doubt that using virtual reality in archaeological reconstructions offers a wide range of possibilities for research, effective guidelines and criteria to regulate such approaches are required.(The London Charter, 2009) A key concern in this area relates to the issue of uncertainty in archaeological interpretations. Post processualist archaeologists have long called for the subjectivity of archaeological interpretations to be taken into consideration, and the theory of uncertainty is now studied in relation to the field of digital archaeology in an attempt to investigate how this could be applied within digital archaeology.

The main aim of this chapter is to theorize the uncertainty of digital archaeological reconstructions within virtual reality environments and to develop a framework to represent that uncertainty using techniques identified in the literature. The first two sections discuss uncertainty as a general theoretical concept and include several definitions of uncertainty and a classification of uncertainty in scientific research. These provide the theoretical basis for the rest of the chapter. The chapter goes on to discuss the uncertainty of digital archaeological reconstructions, including the sources of data, the types of data, the characteristics of data, and the visualization of data. A classification of the factors contributing to the uncertainty within digital archaeological reconstructions is then developed, taking these factors into account. A number of international charters and principles that provide guidelines to be followed in order to address or diminish the uncertainty involved in reconstructions are then introduced, and their application in a number of key case studies is examined. The chapter concludes by proposing a framework for representing the uncertainty of archaeological reconstructions in virtual reality models.

3.2 Defining Uncertainty

Pang defines uncertainty as "*a multifaceted characterization about data, whether from measurements and observations of some phenomenon and predictions made from them. It may include several concepts including error, accuracy, precision, validity, quality, variability, noise, completeness, confidence and reliability*" (Pang, 2001).This definition suggests that there are two main drivers for the uncertainty in scientific research: one related to the data itself and the other dependent on how the data is analysed and the observations drawn from it. However, there is no absolute definition for uncertainty, so the following section considers various definitions found in literature along with definitions of other terms, such as ignorance, incompleteness, imprecision, inconsistency, and error, that were found to be linked to uncertainty and have an impact on it.

Uncertainty arises from one or another form of ignorance, where ignorance is defined as "the state or fact of being ignorant: lack of knowledge, education, or awareness" (Merriam-Webster, 2020b). Bonissone and Tong identify three general categories for expressing ignorance as follows:

1. Incompleteness: refers to cases where the value of a variable is missing;
2. Imprecision: refers to situations where the value of a variable is given, but not with the required precision;
3. Uncertainty: covers cases where an agent can construct a personal subjective opinion on a proposition that is not definitely established for him (Bonissone and Tong, 1985).

These three types represent different cases for *subjective* and *objective* ignorance which can be applied in any field of research, including archaeological reconstructions. So how can they be present in archaeological reconstructions cases? Incompleteness exists, for example, when certain dimensions of an object are given while other dimensions are missing. Imprecision is present, for example, when information about a certain object is given only within a certain range, that is, when the exact dimensions or area are not definite, but what is known is that they fell within a certain range. Uncertainty occurs, for example, when the data entry is done by someone who lacks the required knowledge and skills. In that case, although the data may be precise and complete, there is a possibility that it might be incorrect. The main difference between these forms of ignorance is the degree of participation of agents involved which in turn affects whether an objective or subjective aspect is involved. Incompleteness and imprecision reflect an *objective* form of ignorance. This is due to their reliability on data and context and the fact that neither involves the interpretation of an observer. On the other hand, uncertainty reflects a *subjective* form of ignorance, as it largely relies on the interpretation of the observer. Uncertainty appears when an observer is not certain about the data available, and, as a consequence, depends on personal knowledge or belief.

Smets (1991) also explains different varieties of ignorance through identifying uncertainty. The focus of his research is the imperfection of information and data. He suggests that it is idealistic and almost impossible to expect to have complete information for any computer implemented model, and he highlights the importance of taking imperfection into consideration in any modelling system. Through his research, he identifies three different aspects of imperfect data as follows;

1. Imprecise
2. Inconsistent
3. Uncertain

(Smets, 1991)

High degrees of uncertainty arises from data; this is why Klir and Yuan (Klir and Yuan, 1995) explains that uncertainty is related to faults within data. There are various ways in which errors within data may occur. The data might, for example, be incomplete, vague, or imprecise, all of which contributes to the generation of uncertainty in different ways. Klir and Yuan (1995) identify three different ways in which this uncertainty is manifest;

1. Non-specificity: There are multiple options for the data;
2. Fuzziness: The data is obscure, or there are no specified boundaries or limitations for the data;
3. Discord: There are different alternatives that aren't aligned, creating conflict leading to uncertainty. There are discrepancies in the data.

(Klir and Yuan, 1995)

Gershon also classifies various forms of uncertainty in relation to data, and his classification is perhaps the most comprehensive in that regard. According to Gershon (1998), uncertainty is related to deficiencies with information that could be due to incompleteness, complexity, corruption or inconsistency and can be defined as follows:

1. Corrupt data and information: this represent errors with data related to physics and engineering;
2. Incomplete data and information: this represent data that is missing;
3. Inconsistent data and information: this represent data that is inconsistent in comparison with other data or with previously agreed knowledge;
4. Incomprehensible data and information: this represent complex data that is very difficult to understand;
5. Uncertain data and information: Data and information are known and exist; however the expert is uncertain or uninformed about the quality and existence of the data;
6. Imperfect presentation of data and information: data and information might be accurate and exact; however, the poor presentation of the data might affect how the user interprets the information or data.

(Gershon, 1998)

Although there is no agreed definition of uncertainty in the literature, most focus on uncertainty in relation to data and information itself. Gershon's classification is considered more comprehensive as it also covers the uncertainty generated by the misinterpretation of data, either by the user or the expert, and the uncertainty that arises from a misrepresentation of data by the expert.

3.3 Classification of Uncertainty

Uncertainty is a philosophical concept that overlaps with all aspects of life.(Sorenson, 2016) It remains an important issue in all fields of scientific research, and it has been acknowledged that researchers have an ethical responsibility to try, by every possible means, to decrease the level of uncertainty. This involves putting all possible efforts into gaining deeper knowledge and reaching conclusions based on all available sources of data (Tannert et al., 2007). Just as ignorance can be either objective or subjective, uncertainty has also been classified as either objective uncertainty (aleator)[1] or subjective uncertainty (epistemic)[2] (Sifniotis, 2012). In this classification, aleatory uncertainty comes from a

[1] Aleatory: of, or relating to, accidental causes; of luck or chance; unpredictable.(Merriam-Webster, 2022)
[2] Epistemic: of or relating to knowledge or the conditions for acquiring it.

random process and relates to the randomness and variability that occurs due to probabilistic variability. Aleatory uncertainty is a naturally occurring process which does not occur due to lack of information. However, epistemic uncertainty is strongly related to the data provided, along with the experts' state of knowledge and interpretation of the data. Thus, in the case that all the required data is provided to the interpreter, subjective uncertainty might be eliminated, or at least reduced (Sifniotis, 2012). However, the classification proposed by Sifniotis is strongly related to statistical and mathematical models, and it does not clearly identify and cover all types of uncertainty included within scientific research.

Tannert et.al. (2007) also classify the different types of uncertainty existing in scientific research and also the rationale behind the decision-making for the different types of uncertainty that exist (See Figure 3.1). However, this classification contradicts Sifniotis' approach in determining what is considered as objective uncertainty and what is considered as subjective uncertainty.

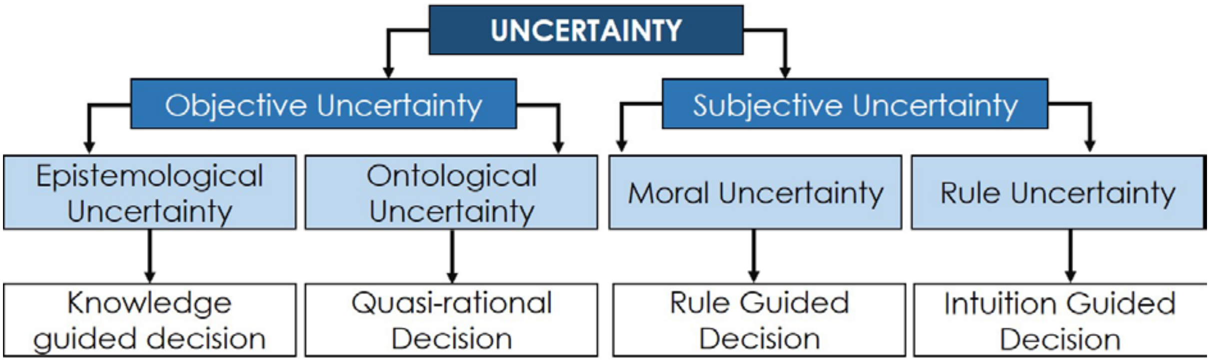


Figure 3.1: The taxonomy of uncertainty and decisions
Source: Tannert, Elvers and Jandrig (2007)

As Figure 1 shows, this taxonomy classifies uncertainty into objective uncertainty and subjective uncertainty, with objective uncertainty then sub-divided into epistemological uncertainty and ontological uncertainty. As epistemology is concerned with the study of knowledge and acquiring more knowledge in order to reach a rationale, epistemological uncertainty means the type of uncertainty that can be eliminated by acquiring more understanding to fill a gap in knowledge. Due to the requirement that a decision should be made at some point in order to take action, the decision is made depending on existing knowledge and any continuing uncertainties are made clear.

On the other hand, Ontology is the philosophical study of being. It is based on the hypothetical elements of any research problem. In this case, the uncertainty arises from complex systems that involve several factors, making it almost impossible to diminish or eliminate the uncertainties using deterministic reasoning. In order to resolve such uncertainties and take decisions, past experience and probabilistic reasoning are used to provide a reference as to how the complex systems might respond. This approach to decision making is defined as quasi rational.[3] (Tannert et al., 2007)

The second main classification of uncertainty is subjective uncertainty, which is influenced by human decisions and based on either morals or rules generated through human judgment. (Campos et al., 2007) According to Tannert et al., (2007), subjective uncertainty can be divided into moral uncertainty or rule uncertainty. Moral uncertainty emerges from research problems where there are no specific moral rules to follow for decision making. In this case, the decision must be made depending on generic rules which don't hold a high degree of satisfaction. Rule uncertainty arises when there are no specific rules to follow. In this case we rely on our own moral judgment, and decision making is based on intuition rather than knowledge. The rationale behind decision making in this case is previously agreed moral principles with support from experimental models (Tannert et al., 2007).

3.4 Uncertainty of Archaeological Reconstructions

Archaeology is a scientific discipline, but it is not an exact science. Much of archaeology is based on building a hypothesis from incomplete data, and there are always different interpretations (Hodder, 1985). The aspect of uncertainty is an undeniable contributor to archaeological interpretations (Bentkowska-Kafel et al., 2012), and the same is true for archaeological reconstructions. The following section focuses on exploring the uncertainty of archaeological reconstructions, especially when using computer-aiding tools. It will begins with the definition of uncertainty in archaeological reconstructions, then goes on to identify the main reasons this uncertainty occurs, before considering the recommendations found in various charters and principles to minimize such uncertainty or resolve it.

Archaeological uncertainty has been defined as "*an archaeological expert's level of confidence in an interpretation deriving from gathered evidence*" (Sifniotis et al., n.d.) However, while this definition focuses on the contribution of the expert, the data itself can contribute greatly to the uncertainty. The uncertainty arises from multiple sources of data and the various ways of interpreting them. (Sorenson, 2016)The interpretation and hypothesis are based, in many cases, on the specialists' point of view, which increases the element of subjectivity. However, in other cases, acceptable documentation is provided and the interpretation can then be traced, which bolsters the certainty of that interpretation to

[3] Quasi-rational: is to include consideration of hunches, intuition, and tacit knowledge, often embodied in stories that have meaning to the decision-maker.

some extent. The various interpretations associated with any particular site could therefore be divided into several subgroups, depending on the degree of certainty they provide. These different groups could then be visualized using digital models to show the different degrees of uncertainty, as has been demonstrated in previous research (Apollonio, 2016)(Kensek et al., 2004);(Houde et al., n.d.).

3.4.1 Types of Data

Archaeological interpretations are always limited by the quantity and quality of both the historical and archaeological data available (Murgatroyd 2008). These limitations have a direct influence on the level of certainty of the archaeological interpretations. As a consequence, there is always a degree of uncertainty and, in some cases, this leads archaeologists to create different hypotheses (Eiteljorg, 2000). This section expands on the general definitions set out above to determine how this is applied in the flow of data through the archaeological reconstruction process.

The complexity of digital archaeological reconstructions requires a clear differentiation between input data, output data, para data and meta data. Input data in the digital reconstruction of archaeological sites is defined in this research as “All available evidence related to the archaeological site”, while output data is “The digital reconstructed model that is generated based on the existing evidence about the archaeological site”. Para data is defined in the London Charter as “*Information about human processes of understanding and interpretation of data objects*” and examples include *“descriptions stored within a structured dataset of how evidence was used to interpret an artefact, or a comment on methodological premises within a research publication*” (The London Charter, 2009). Para data in this context represents data that explains the process of interpretation of archaeological evidence and data that explains the reconstruction process that was followed. This data is not generated to be communicated to end users, but it is normally archived for experts’ use or for future research. Contextual meta data, by contrast, is defined in the London Charter as “*intend to communicate interpretations of an artefact or collection, rather than the process through which one or more artefacts were processed or interpreted*” (The London Charter, 2009). Within the virtual reconstruction of archaeological sites, meta data is the data integrated into the reconstructed model which is used to communicate the evidence that was used to support the interpretation to the user. The tools through which this data could be communicated to end users are explained in the case studies later in this chapter.

Due to the increase in using digital tools and applications, both meta data and para data are becoming more important issues in the design, use, management, diffusion and archiving of archaeological models. This means that it is now essential that both the data used for the modelling “meta data” and the process of reconstruction "para data" are made clear for both experts and the public during the archaeological reconstruction process (Brusaporci, 2017). Figure 3.2 explains the flow of data and how each type of data forms a part of the virtual reconstruction of archaeological sites. The meta data is considered as the aspect that differentiates the digital reconstructed models in general from the integrated models, whether the integrated models are used within virtual reality environments or not.

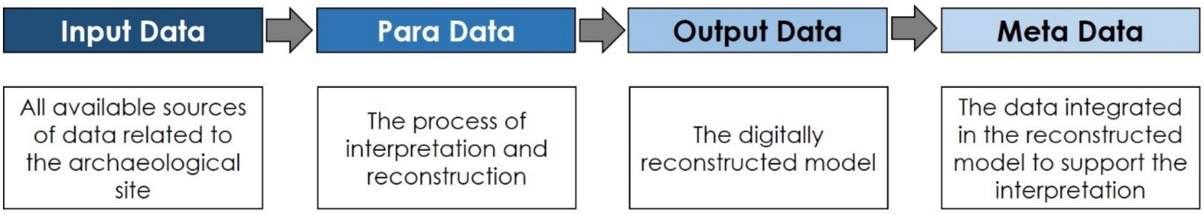


Figure 3.2: Types of data and their manifestation in the virtual reconstruction of archaeological sites
Source: Created by the Author

3.4.2 Sources of Data

The archaeological reconstruction process is not the same across all contexts. It has changed over time and is different from one archaeological school to another. In addition, experts from different backgrounds will follow different approaches. Not only is the process different, but the type, quantity, and quality of data available for each archaeological site is also different. Experts can base their reconstructions on various evidence types, and the case studies explored in the literature review demonstrated a range of different types of evidence used in archaeological reconstructions. The types of evidence are classified by the author through reviewing a large number of journal articles that cover the digital reconstruction of archaeological sites. This includes work by Ferdani et al., Ortiz-Cordero et al., Smith et al. , Di Maio et al. and Palomar et. al. (Ferdani et al., 2020); (Ortiz-Cordero et al., 2018); (Smith et al., 2017); (Di Maio et al., 2018); (Palomar et al., 2020). The first type of evidence is the actual remains from the site, and it can be classified as follows:

1. Architectural Features: Including all complete structures or parts of structures that form either walls, roofs or flooring. This could include, for example, parts of columns, doors, niches etc;
2. Archaeological Artefacts: Including any objects manufactured, used, and abandoned by human beings. This could include for example tools, textile, furniture, cooking utensils etc;
3. Archaeological Biofacts: Including any organic remains found on an archaeological site that is not altered by human beings. This could include human and animal bones, plant seeds, uncarved wood etc.

The second type of evidence is historic data, which could be classified as follows:

1. Textual Evidence: Including all historic texts and documents about the site, such as descriptions of both physical aspects, such as architectural style, architectural scale, and building materials, and non-physical aspects, such as lifestyle, culture etc.
2. Visual Evidence: Including all maps, drawings, and photographs that are relevant to the site or the surrounding context.

The third type of evidence is related to the contextual study of the site and includes the following:

1. Geographic and Geological Context - Topography and Landscape: Including natural characteristics of the site, such as the topography of the site, landform data, geological data and local materials.
2. Historic Context: Including studying similar structures within similar contexts and comparing them to the site of the case study.

In addition to relying on various types of evidence, based on each case study and the specific aims of each project, either one or more experts would be involved in the reconstruction process.This was concluded from reviewing the team that contributed in the different projects and research work that was reviewed. (Ferdani et al., 2020);(Ortiz-Cordero et al., 2018);(Smith et al., 2017)(Di Maio et al., 2018); (Palomar et al., 2020) As the interpretation and hypothesis proposed is affected by each expert's background, the reconstructions usually undergo peer review by other specialists in order to test their reliability. However, whether a reconstruction attempt has been through a peer review process or not, whether it involved one expert or multiple experts, and whether the expertise involved was interdisciplinary or not, the subjectivity of the interpretation has an impact on the final reconstructions.

3.5 Classification of Factors Contributing to the Uncertainty in Digital Archaeological Reconstructions

Having examined the meaning and classification of uncertainty as an important aspect in scientific research and then within archaeological reconstructions, this section presents a novel theoretical framework for theorizing uncertainty of digital archaeological reconstruction (See Figure 3.3). The framework is based on Tannert et al.'s (2007) classification of uncertainty and attempts to classify the different definitions and types of uncertainty in archaeological reconstructions within this generic classification. The decision rationale for each type of uncertainty can then be applied to digital archaeological reconstructions. This framework would therefore be beneficial for experts in taking decisions regarding uncertainties within archaeological reconstructions as well as in making these uncertainties clear to end users.

The flow of data from the existing data to the generation of the virtual model is also explained through this framework. Input data is explained as the existing evidence about the archaeological site, which affects objective uncertainty, while the para data is the process of the interpretation of the archaeological evidence, which is influenced by human factors and affects subjective uncertainty. Both input data and para data are combined to generate the digital archaeological reconstruction model, which is defined as output data. The integration of meta data within the output model adds further knowledge, which is the main contribution that diminishes the uncertainty of archaeological reconstructions.

3.5.1 Characteristics of Data

Each of the previously mentioned sources of data, whether actual remains, historic data, or contextual data, carries a number of characteristics that have an influence on the virtual reconstruction of an archaeological site. Brusaporci identifies the main characteristics that affect the final model as: "type of source, source completeness, source reliability and the level of interpretation of sources" (Brusaporci, 2017), and these could be applied to any of the data sources previously identified (See Figure 3.4). These characteristics are used to determine which type of data has a higher priority for consideration in the reconstruction process. An example of how the type of source has an impact on uncertainty would be the fact that an actual remain would be considered to have a higher degree of reliability than a historic map or drawing. An example of source completeness would be the fact that a whole column would be considered more reliable than a fragment of a column. As for source reliability, if two historical resources include the same information then there is consistency within the historic data, which gives a higher degree of reliability. And for level of interpretation, the involvement of expertise from various disciplines in a peer review process generates a higher degree of reliability.

In archaeological reconstructions, each specific case study will be treated differently, and the types of sources used will be different. In addition, the representation of the degree of reliability will take different forms, depending on the aim as well as the target users. The precise forms will depend on the type of sources available and the aim of the reconstruction, as explained in the following sections.

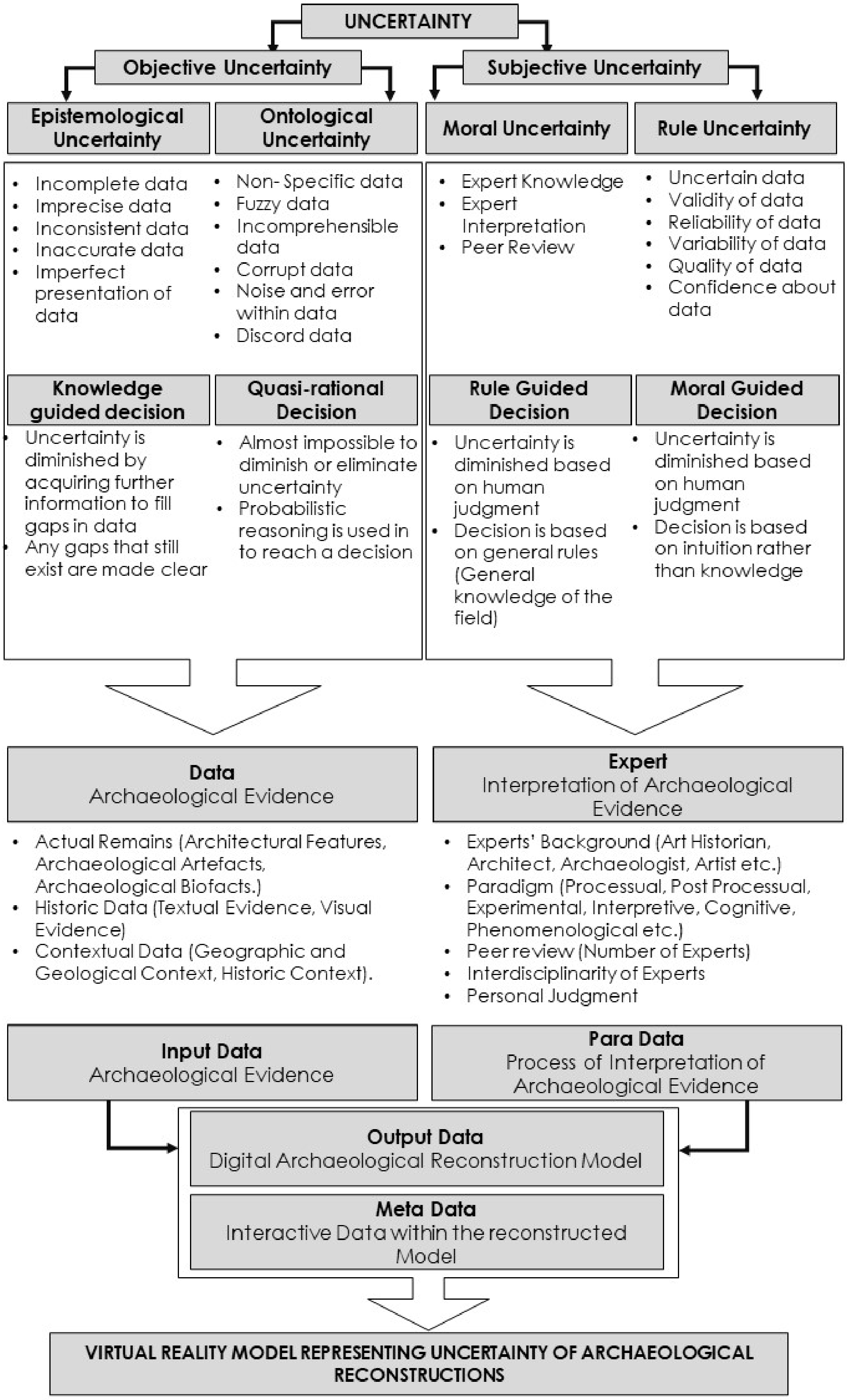


Figure 3.3: Framework for theorizing uncertainty in archaeological reconstructions.
Source: Created by the Author

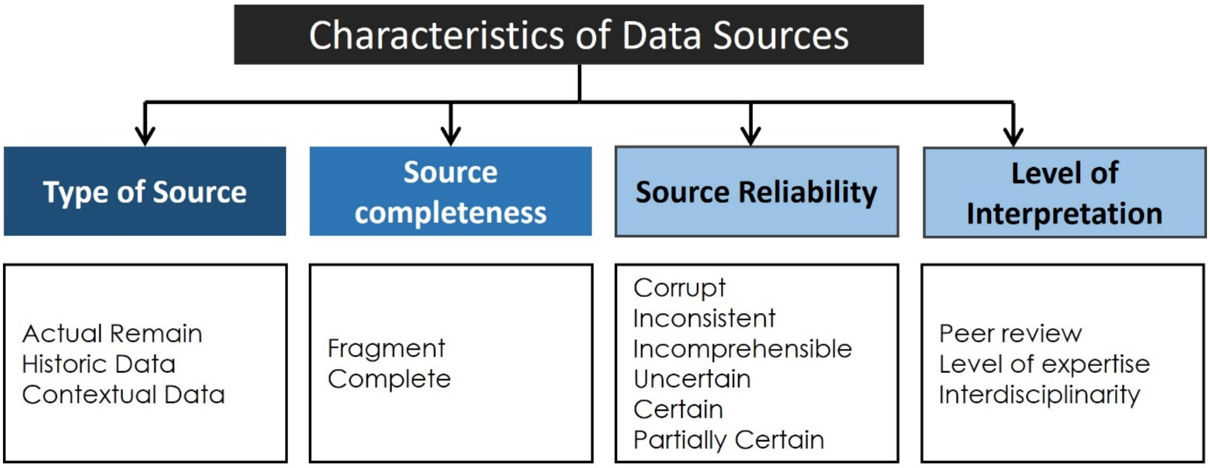


Figure 3.4: Characteristics of Data Sources in The Digital Reconstruction of Archaeological Sites. Source: Created by the Author

3.5.2 Visualization of Data

In order to use digital technologies to create virtual reconstructions of archaeological sites, the data is processed in the form of 3D modelling. The 3D modelling process takes different forms, and there are different approaches for both the modelling and the rendering of the reconstructions. The aim of this section is not to focus on the software used or the technological process involved but rather to highlight the features within the 3D models that could be used to represent different degrees of uncertainty or reliability. Reliability has been defined as "the quality or state of being fit to be trusted or relied on" (Merriam-Webster, 2020c), but how this quality can be measured and represented in modelling is a matter of some debate. However, Brusaporci suggests that the degree of reliability can be reflected in 3D models in the following features "(1) Geometry, (2) Location/Position, (3) Date/Age, (4) Colour/Texture, (5) Material/Constructive system, (6) Context (Urban-Rural-Natural/Landscape)" (Brusaporci, 2017), and Apollonio determines that the uncertainty in reconstruction models can be best represented in the following: "(1) Shape (geometry, size, spatial position), (2) Material (Physical form, stratification of building/manufacturing system" (Apollonio, 2016). These features can then be visualized using different methods to represent different degrees of reliability.

Confidence is another concept that is considered measurable and could be used for visualization. Confidence is defined as "the quality or state of being certain" (Merriam-Webster, 2020a), and Kensek has classified the methods used for presenting the degree of confidence visually as follows:

1. colouration schemes (for example, green = confident, yellow = medium confident, red = not confident; shades or saturation of a colour; black and white versus colour)
2. patterns, hatches, line types;

3. materials;
4. rendering type
5. transparency (opaque confident, different levels of transparency for less confident)

(Kensek, 2007)

A visual representation of this classification is shown in Figure 3.5.

Figure 3.5: Different visualization modes for presenting uncertainty in 3D models, colorization, textures and transparency Source: Created by the Author based on Kensek (2007).

From the above it is clear that the visualization of uncertainty is actually a visualization of certainty, as researchers are only capable of visualizing and representing what they are certain about. This is why terms such as reliability and confidence often appear in literature related to this field of research. Examples of the ways these different visualization modes have been applied in case studies are provided later in the chapter.

3.6 Charters and Principles Addressing Uncertainty in Archaeological Reconstructions

Efforts to establish globally accepted principles for the protection, preservation, and restoration of heritage and archaeological sites around the world have led to the development of a number of charters and principles by experts within the field, notably the International Council on Monuments and Sites (ICOMOS). With the introduction of computer-based visualisation of cultural heritage, new principles addressing the use of these new technologies in researching and communicating cultural heritage were required. This was necessary in order to ensure methodological rigour, with a specific focus on the importance of "intellectual transparency" in using computer-based methods to communicate information related to archaeological and heritage sites. (Brusaporci, 2017) This section covers the main charters addressing aspects of "uncertainty" and "transparency" and explains the need to take them into consideration while using computer-based visualisation in the field of cultural heritage.

One of the most important charters is the *London Charter for the Computer-based Visualisation of Cultural Heritage*, which was conceived in 2006, based on a symposium entitled "Making 3D visual research outcomes transparent" which was held at The British Academy in London. The London

Charter specifically aimed to "*establish principles for the use of computer-based visualization methods and outcomes in the research and communication of cultural heritage*" (The London Charter, 2009), and it includes a list of principles and guidelines which should be applied in any cultural heritage related project that involves the use of computer-based visualization methods. The issue of uncertainty is not often mentioned in the charter; however, there is a clear reference under "Principle 4: Documentation", which states that: "*It should be made clear to users what a computer-based visualisation seeks to represent, for example the existing state, an evidence-based restoration or an hypothetical reconstruction of a cultural heritage object or site, and the extent and nature of any factual uncertainty*" (The London Charter, 2009). Although the above text reflects the importance of addressing the issue of uncertainty in heritage reconstructions and clarifying the hypotheses that were used to generate these visualizations, the description is very general, and it does not indicate how this kind of uncertainty should be represented. Indeed, the London Charter discuss uncertainty only in an indirect way by indicating the necessity of documentation of research sources, process, methods and dependency relationships, as this kind of clear documentation might eventually provide supporting evidence that would prevent misinterpretations.

A further set of principles to regulate the use of virtual reality in the field of archaeology were developed in Seville, Spain. Officially entitled *The Principles of Seville: International Principles of Virtual Archaeology,* but more commonly known as "The Seville Principles", these are based on the general principles of the London Charter but with specific focus on virtual reality and were ratified by the 19th Icomos General Assembly in New Delhi in 2017 (Icomos General Assembly, 2017). The term "uncertainty" is not explicitly mentioned in any of the principles; however, other relevant terms are mentioned, including "authenticity" and "transparency", which are strongly linked to the uncertainty of archaeological reconstructions.(Bentkowska-Kafel et al., 2012)(Brusaporci, 2017) For example, Principle 4 describes 'authenticity' in the following terms:

> *Computer-based visualisation normally reconstructs or recreates historical buildings, artefacts and environments as we believe they were in the past. For that reason, it should always be possible to distinguish what is real, genuine or authentic from what is not. In this sense, authenticity must be a permanent operational concept in any virtual archaeology project*.
>
> (Seville Principles, 2011)

As in The London Charter, this principle sets out the expectation that the differentiation between what is real and authentic and what is not needs to be made clear in digital reconstructions. However, subsections of this principle set out different means of achieving this as follows;

> 4.1 *Since archaeology is complex and not an exact and irrefutable science, it must be openly committed to making alternative virtual interpretations, provided they afford the same scientific validity. When that equality does not exist, only the main hypothesis will be endorsed.*
> (Seville Principles, 2011)

This point underlines the need to provide alternative interpretations for archaeological sites, thereby providing the user with an understanding that a degree of uncertainty exists regarding the reconstruction provided. It indicates, however, that the alternatives should provide the same degree of validity, and this is rarely the case with archaeological reconstructions. As a result, the principles go on to require that users are given information regarding the reliability of the reconstruction in order overcome this issue:

> 4.*2 When performing virtual restorations or reconstructions, these must explicitly or through additional interpretations show the different levels of accuracy on which the restoration or reconstruction is based.* (Seville Principles, 2011)

Different ways in which this could be achieved are presented in the following sections in relation to applied research work:

> 4.3 *In so far as many archaeological remains have been and are being restored or reconstructed, computer-based visualisation should really help both professionals and public to differentiate clearly among: remains that have been conserved "in situ"; remains that have been returned to their original position (real anastylosis); areas that have been partially or completely rebuilt on the original remains; and finally, areas that have been virtually restored or reconstructed.* (Seville Principles, 2011)

This principle highlights the importance of giving even more information and data about the different sections of the archaeological reconstructions and where they are located in reality.

Other charters that set guidelines for the reconstruction of cultural heritage or archaeological sites also discuss the issue of uncertainty in archaeological interpretations and reconstructions, regardless of the media used for representation. For example, the *ICOMOS Charter for the Interpretation and Presentation of Cultural Heritage Sites* (2008) sets out the following in Principle 2: Information and Resources:

> *Visual reconstructions, whether by artists, architects, or computer modelers, should be based upon detailed and systematic analysis of environmental, archaeological, architectural, and historical data, including analysis of written, oral and iconographic sources, and photography. The information sources on which such visual renderings are based should be clearly documented and alternative reconstructions based on the same evidence, when available, should be provided for comparison.*" (ICOMOS, 2008)

These considerations are also valid in the case of digital reconstructions of archaeological sites, where the need to utilise all available resources, including written texts or visual materials, to supplement the remaining artefacts is essential. The necessity of including alternative reconstructions clearly highlights the need to represent the aspect of uncertainty in the interpretations. In that regard, digital reconstructions actually provide a greater degree of flexibility in comparison with physical reconstructions. They offer the possibility of generating several alternatives, something that physical reconstructions generally lack. In addition to that, virtual reality as a medium creates numerous applications that allow the navigation from one interpretation to another, whilst supporting each interpretation with the relevant historical, archaeological and architectural data.

Another charter that addresses the reconstruction of archaeological sites is *The Charter of Krakow: Principles for Conservation and Restoration of Built Heritage*, which was the outcome of the International Conference on Conservation in Kraków, Poland in the year 2000. The aims and methods section of this charter recommends that *"The reconstruction of entire parts 'in the style of the building' should be avoided"* (Charter of Krakow, 2000), clearly identifying that it is preferable to be able to distinguish real parts from reconstructed parts. However, the aspect of style could be taken into consideration in a digital reconstruction if the reconstructed parts could be represented differently visually, for example by using photorealistic and non-photorealistic rendering. In this respect, digital reconstructions are preferable to physical reconstructions because the virtual media, by default, is a different style of representing the past in itself. Just generating a digitized reconstruction would give the viewer a sense that the reconstruction has a degree of uncertainty and virtuality within it.

In conclusion, these international charters and principles identify the following considerations which need to be taken into account in any attempt to visualize a heritage or archaeological site using computer-based visualization methods:

- Visual reconstructions of any archaeological site should be based on credible information including environmental, archaeological, architectural and historic analysis;

- Visual reconstructions of any archaeological site should be based on all available types of resources, including textual, oral , iconographic, photographic and visual data;
- Users should be provided with a clear explanation of what the visualization aims to represent, whether it is an existing state, an evidence-based reconstruction, or a hypothetical reconstruction;
- It should be clear to the user which parts of the reconstructed model are real, genuine, and authentic and which parts are not;
- Different rendering styles should be used to differentiate between real parts and reconstructed parts;.
- Users should be provided with a precise representation of the degree of certainty or ambiguity for the different parts of any reconstructed model;
- Generating alternative interpretations for the reconstruction of archaeological sites should be attempted, whether they are based on the same evidence or conflicting evidence;
- Efforts must be taken to ensure that the degree of credibility and scientific validity for these different interpretations is clear to the user;
- The respective levels of accuracy of the different interpretations needs to be clear to the user along with clear information about the credibility of the data they were based on;
- Users should be provided with all textual, oral, iconographic, photographic and visual data available that supports the digital reconstruction;
- Data provided regarding the remains that were used for developing the reconstruction model should include: where they were gathered from; whether the remains were conserved in-situ, conserved elsewhere, returned to their original location (real anastylosis), built on top of existing remains, or virtually restored or reconstructed.

3.7 Virtual Representation of Uncertainty

Visual models are of great importance for understanding and communicating the past, especially with the public; however, they may also lead to false interpretations, especially if uncertain and inexact information or vague assumptions are visualized (Danielová et al., 2016). This is why it is crucial to include the factor of uncertainty in visual archaeological reconstruction models. This section focuses on the representation of the uncertainty of archaeological reconstructions in virtual reality environments by exploring how this approach has been applied in previous research with the aim of determining gaps in current knowledge. Most of the research conducted to date has focused on the representation of uncertainty in the modelling of 3D reconstructions, so that is discussed first.

Research on investigating how the interactivity and immersion within virtual reality environments could be used to represent the uncertainty of archaeological reconstructions is very limited, but the few studies which exist are discussed in the second part of the section.

3.7.1 Modelling

One approach to representing the uncertainty of digital reconstructions of archaeological sites focuses on the different modes of 3D visualization. This approach is applied to digital 3D reconstructions and the models are used either in VR or in other multimedia displays. A key discussion in this area is whether the use of photorealistic or non-photorealistic modelling is best to represent uncertainty, with some work using different textures, colours, or transparency levels (Kensek et al., 2004) (Olivito and Taccola, 2014)to highlight the degree of uncertainty and reliability of the different sections of the reconstruction model.

Eiteljorg was one of the first researchers to raise concerns about the level of detail that virtual heritage models present to the user, making the point that photorealistic visualizations appear to present a 'real' and fixed view of the past (Eiteljorg, 1995). Eiteljorg highlighted the importance of creating models in which it is easy to distinguish between the real and the hypothetical, and his work on reconstructing the Acropolis Propylaion (See Figure 3.6) demonstrates this focus on visualizing the difference between the real and the reconstructed (Eiteljorg, 1995)(Eiteljorg, 2000).

Figure 3.6:The Acropolis Propylaion Reconstruction showing the difference between using the same texture for the whole wall on the left and the differentiation between the remains and the reconstruction using a white line on the right.
Source: Eiteljorg,(2000, n.p).

Roussou, in her research, focuses on investigating the differences between photorealistic renderings versus non-photorealistic renderings in archaeological reconstructions and concludes that both could contribute to the field of heritage reconstruction and visualization in different ways (Roussou, n.d.). The choice between them normally depends on the target audience: researchers, archaeologists or the public. Both archaeologists and researchers require visualizations that would help them to reach certain hypotheses or find different interpretations, and this could best be achieved using non-photorealistic renderings. Meanwhile, photo realistic visualizations are considered the most appropriate technique to aid in the engagement of the public (Roussou, n.d.). However, the degree of photorealism strongly affects the notion of certainty attached to archaeological reconstructions. When photorealistic renders are used, users are less likely to realize that there might be a different interpretation, and thus a different reconstruction, of the same site, while the use of simplified models creates a sense that they are just a virtual representation of reality.

Kensek et al. (2004) discuss different ideas concerned with the ambiguity, evidence, and alternatives in virtual reconstructions of archaeological sites. Their research focuses on the importance of differentiating between what is real and what is speculative and presents different methods to reach this through various visualizations. Different modes of representing this ambiguity and uncertainty are presented, including using different colours and different levels of transparency (Kensek et al., 2004). The visualization modes presented below are the same as those mentioned in another work by Kensek (Kensek, 2007) and provide a clear example of the various modes of rendering which can be used on the same model (See Figures 3.7 – 3.10).

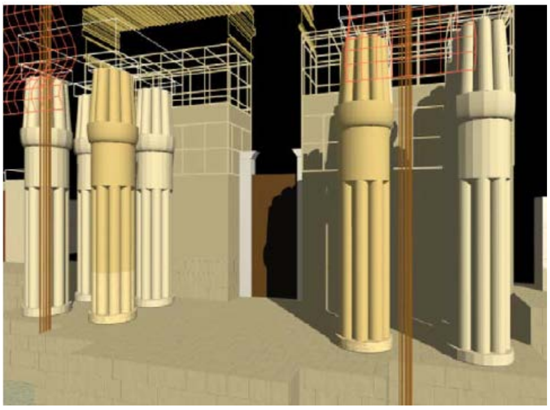


Figure 3.8: A reconstruction using varying opacity values as a key for confidence levels. Greater opacity implies a higher level of confidence in the reconstruction.
Source: Kensek et al. (2007)

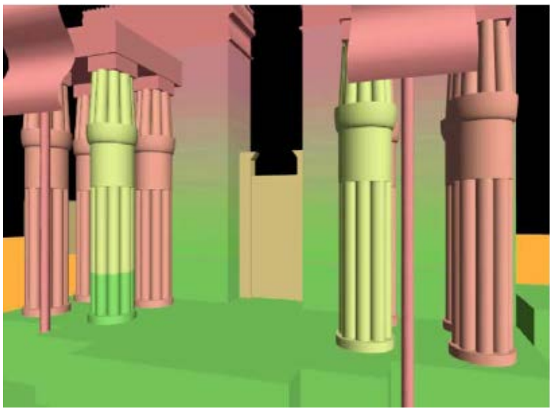


Figure 3.7: A false colour version that shows the level of confidence in various sections of the model. Green hues imply greater confidence, while red implies less confidence. Darker hues imply greater confidence than lighter hues.
Source: Kensek et al. (2007)

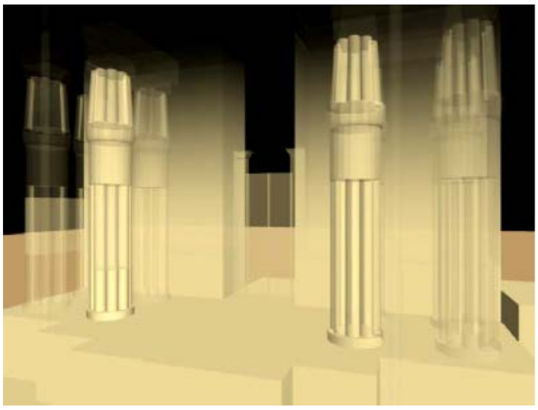


Figure 3.10: A mixture of rendering types. The wire frame portion is the most tenuous part while the more realistically rendered portions have a higher level of confidence.
Source: Kensek et al. (2007)

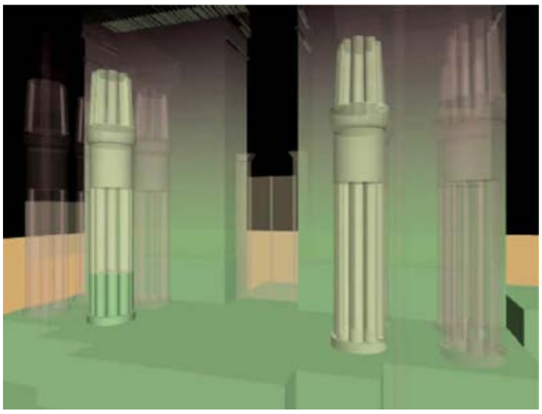


Figure 3.9: A hybrid system using both false colour and varying opacity levels.
Source: Kensek et al. (2007)

Another approach to visualizing uncertainty is proposed by Olivito and Taccola (2014). They present an approach for integrating reality-based procedures with non-photorealistic modelling for the missing sections of the agora of Segesta, an ancient Greek city on the western slope of Sicily. The documentation of the existing parts of the agora was done using photogrammetry, both terrestrial and aerial, and the researchers used mixed representation styles to elaborate the uncertainty of the reconstruction. This was done by using simple non textured geometric forms overlaid on the real photogrammetric modelling of the remains (Olivito and Taccola, 2014) (See Figures 3.11 and 3.12).

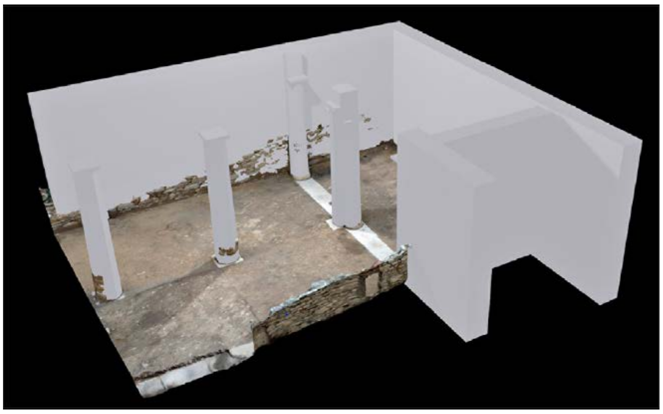


Figure 3.11: N-E corner of the stoa: 3D reconstruction overlaid on the reality-based model
Source: Olivito & Taccola (2014)

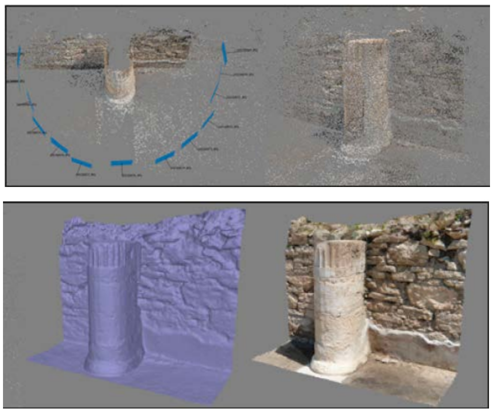


Figure 3.12: Photogrammetric pipeline showing images acquisition to textured model
Source: Olivito & Taccola (2014)

The main research aim was to demonstrate the techniques used in the data collection, the elaboration, and the interpretation in a project for archaeological investigation of the agora. However, the study also presents another modelling technique that is now widely used in digital reconstructions of heritage or archaeological sites to differentiate the parts that already exist on site and the virtual reconstruction of the parts that have been lost.

Sifniotis (2012) aims to explore, describe, quantify and visualise uncertainty in cultural informatics while focusing on archaeological reconstructions as an application. The research focuses on generating three different mathematical models for quantifying uncertainty in archaeological reconstructions. This is followed by several proposals for visualizing uncertainty using different modelling and rendering approaches. The system generated creates the possibility of providing different probabilities for uncertainty, and these are represented with different degrees of transparency in the modelling (Sifniotis, 2012) (See Figure 3.13Error! Reference source not found.).

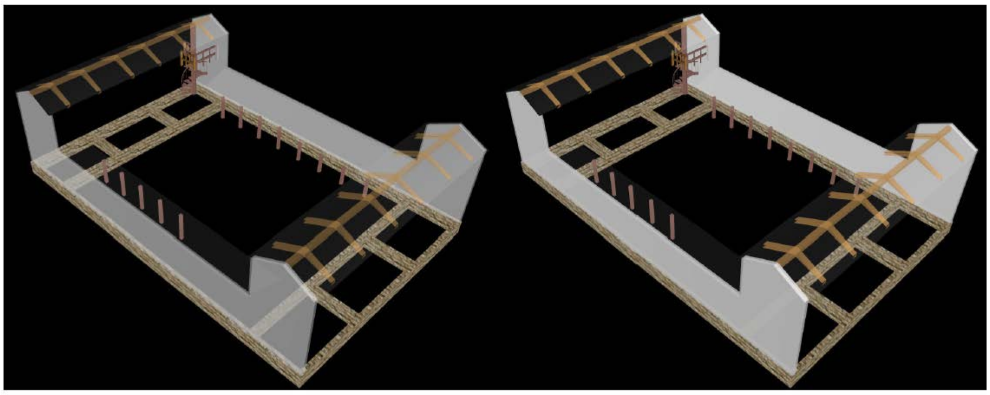


Figure 3.13: Different degrees of transparencies that represent the uncertainty of the reconstruction Source: Sifniotis (2012, p. 141)

3.7.2 3D Visualizations

Other research work has focused on studying how qualitative uncertainty could be represented in 3D visualizations. In their research paper, Houde, Bonde and Laidlaw (n.d.) present a project that included the visualization of uncertainty in both architecture and archaeology. The work was a collaboration between an architectural historian/archaeologist and a computer scientist to explore qualitative uncertainty. Qualitative uncertainty identifies certainty levels not by specific measurements, but by the past knowledge of human beings. The site of the project is the charterhouse of Bourg Fontaine, a Carthusian monastery northeast of Paris which was constructed in 1323-1325. The great cloister, which was once part of the site, has now disappeared completely , along with all its cells, and previous work was done on site, including ground penetrating radar surveys for the area. (Houde et al., n.d.)

The main aim of this research was to explore a method that makes it possible for both researchers and the public to perceive the different levels of uncertainty in archaeological and architectural reconstructions, and the outcome was to compare three modes for visualization of uncertainty. The representations included using transparencies, wireframe modelling and colours, so the three variants were a colour model, a transparent model and a textured version. In the coloured model, each colour represented a different certainty level. The same colours were used for the transparent model, but the opacity of each certainty level was different. The third model used various different monochromatic textures to represent different levels of certainty (See Figure 3.14).

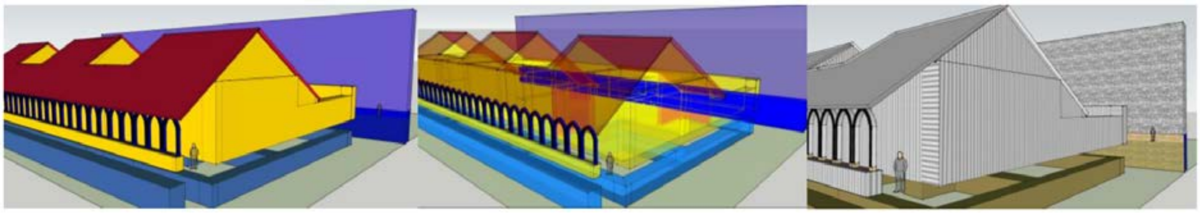


Figure 3.14: The three variants of the model generated (from left to right): colour, transparency, and texture. Source: Houde et al., (n.d.). Available online at https://goo.gl/wj8q4g

The clarity, simplicity, and usefulness of these models were evaluated through an online survey which asked users, both professionals and students, to respond to four simple statements for each model, as follows:

1. The 3D rendering is simple to interpret (*simplicity*)
2. The difference in uncertainty among features is clear (*difference*)
3. The model is clear in representing uncertainties (*clarity*)
4. I would find a model like this one to be useful in my work or research (*useful*).

(Houde et al., n.d.)

The colour model was considered the most favourable, with a slight advantage over the transparency model. The texture variant was considered the least favourable. One of the reasons for that was that the textures were very similar, and it was very hard to distinguish between them (Houde et al., n.d.). The responses received for the preferred models are provided in Figures 3.15 and 3.16 below.

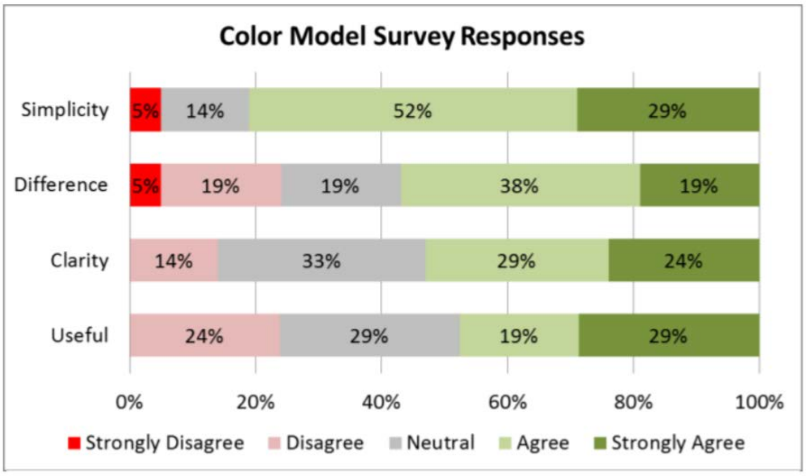


Figure 3.15: Colour Model Survey Responses
Source: Houde, Bonde & Laidlaw (10 March 2016)

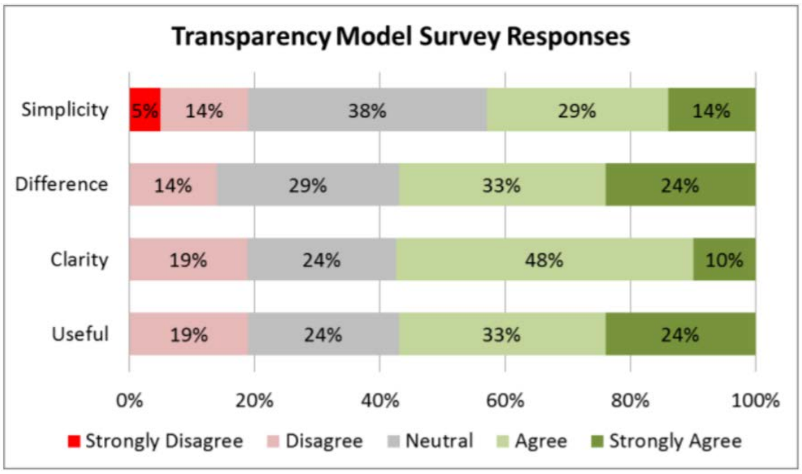


Figure 3.16: Transparency Model Survey Responses
Source: Houde, Bonde and Laidlaw 10 March 2016

While this study follows a very similar approach to Kensek's work, the surveys conducted with professionals and students to evaluate the different models give a deeper insight into which method of representation is most effective and useful for the users.

Research by Ortiz-Cordero et al. (2018) explores the representation of different degrees of knowledge in the reconstruction of the mosque-cathedral in Cordoba, Spain. The research is based on modifying the chromatic scale of evidence generated by Tayfun Öner for the Byzantium 1200 project team to take both the London Charter (2009) and Seville Principles (2011) into consideration. The main aim for the change of colour scale was to focus attention on the reconstructed sections and to ensure that future models are clear, aesthetic and scientifically rigorous (Ortiz-Cordero et al., 2018). The two chromatic scales are shown in Figures 3.17 and 3.18, and a series of four models comparing them is provided in Figure 3.19.

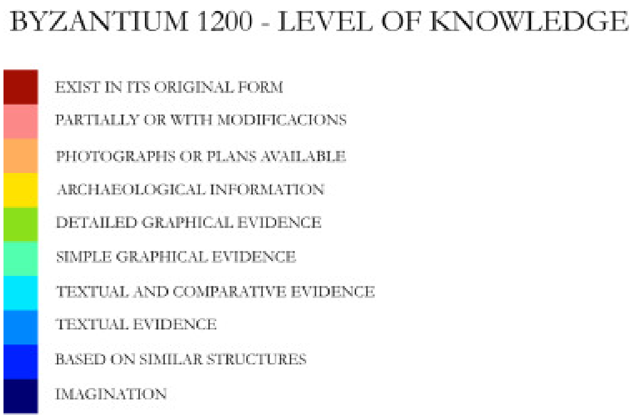
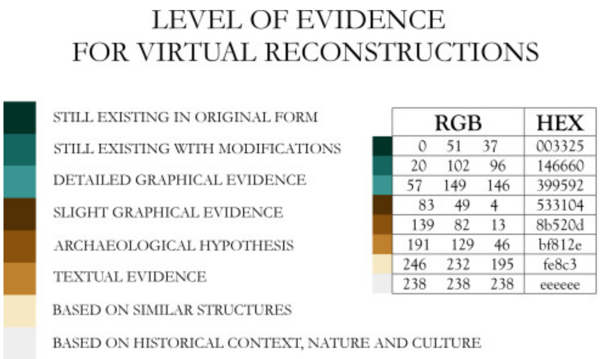


Figure 3.17: Byzantium 1200 scale of knowledge for virtual reconstructions.
Source: Tayfun Öner



RGB			HEX
0	51	37	003325
20	102	96	146660
57	149	146	399592
83	49	4	533104
139	82	13	8b520d
191	129	46	bf812e
246	232	195	fe8c3
238	238	238	eeeeee

Figure 3.18: Proposed scale of evidence for virtual reconstructions.
Source: Ortiz-Cordero et al. (2018)

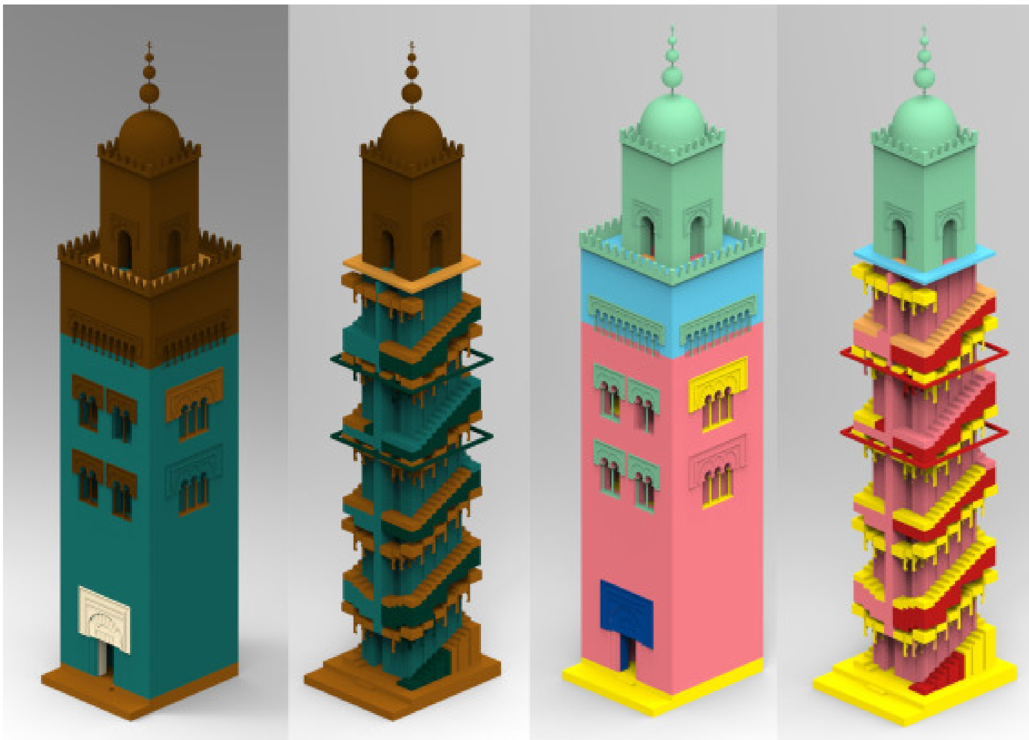


Figure 3.19: A comparison of the proposed scale of evidence (to the left) with the original scale proposed by Tayfun Öner for Byzantium 1200 (to the right). Source: Ortiz-Cordero et al. (2018)

These sections have presented the most important research work on representing uncertainty in the modelling of virtual reality reconstructions. It has focused on giving examples of using various rendering types, such as photorealistic and non-photorealistic renders, and different methodologies, quantitative, qualitative, or mixed methods. Each study focused on one or more of the considerations discussed in the charters and principles described above, but the process undertaken in the reconstruction was different, depending on the resources available and the aim of each project. For example, when the target user is the general public, it might not be necessary to give exact values for the uncertainty; simply providing the user with multiple interpretations would be sufficient to deliver the message that other interpretations are possible. On the other hand, if the target users are researchers and experts in the field and the models are generated for research purposes, it might be more important to give exact statistical or numerical data that signify a specific degree of uncertainty.

These examples are just a sample of multiple projects that consider how uncertainty could be represented in the modelling of digital archaeological reconstructions. Virtual reality, however, does not just rely on generating 3D models that are presented to the user through a screen. Virtual reality differs in that the user is immersed into the environment which has been created, and they can even be allowed to interact and change elements within it. As a result, the following sections discuss projects that included the extra features within virtual reality environments.

3.7.3 Interactivity and Immersion

Virtual reality offers the possibility of interaction within immersive environments which could be used to represent the uncertainty of archaeological reconstructions. However, research is only just beginning to explore the possibility of using interactivity in this way, although some have examined the difference between photorealistic and non-photorealistic rendering in interactive virtual reality environments. For example, Gaitatzes, Christopoulos and Rousso (2001) discuss the difference between high level detailed reconstructions of heritage sites and non-realistic modelling that focus more on interactivity. They present several case studies, including "The reconstruction and virtual journey through the ancient city of Miletus by the coast of Asia Minor", the reconstruction of "The Temple of Zeus at Olympia", "The Magical World of Byzantine Costume", and the "Olympic pottery puzzle". The details of each of these cases are discussed below.

The reconstruction of the ancient city of Miletus focused on providing photorealistic renders that allow users to navigate through a virtual reality experience, and the model is presented as an example of an accurate, detailed reconstruction of the site (Gaitatzes et al., 2001) (See Figure 3.20 and 3.21). There is no representation of uncertainty within this case study, and the use of photorealistic renders and the lack of interactivity give the impression that the reconstruction is real. In addition, there is no study of how immersion in the virtual reality environment impacts the user in terms of realizing the degree of reliability of such an interpretation, and the data sources, such as archival, historic or contextual data are not imbedded within the model.

Figure 3.21: View of the Temple of Zeus at Olympia Source: Gaitatzes et al. (2001)

Figure 3.20: View of the Bouleuterion, a public building of Miletus. Source: Gaitatzes et al. (2001)

The second case study, "The Temple of Zeus at Olympia", does not offer high level of details, but it includes the integration of multimedia representing the battle between the people of Lapithes and the Centaurs, thought to symbolise the fight between Reason and Instinct (Gaitatzes et al., 2001). In this case study, further intangible data is included within the virtual model, and this addresses the issue of transparency, as it provides the user with the historic background that is essential for a better understanding of the visualization attempt. The aspect of uncertainty of archaeological reconstructions is not directly investigated in this research; however, the use of different modelling and interactivity techniques and how this impacts user understanding of the site is addressed.

The third case study, "The Magical World of Byzantine Costume", allows a more flexible approach to reconstruction and does not aim to represent a rigid, known, 'reality' of the past. It emphasizes interactivity rather than a highly detailed reconstruction and is designed to be an educational and experimental experience for children (see Figure 3.23) (Gaitatzes et al., 2001).

Figure 3.22: View of the magical world of Byzantine Costume. Source: (Gaitatzes et. al.,2001)

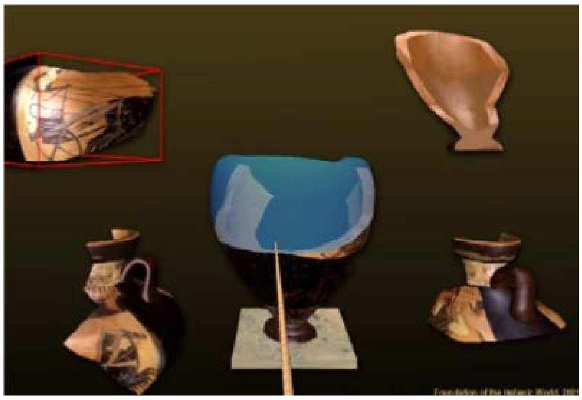


Figure 3.25: View of the Olympic pottery puzzle project. Source: (Gaitatzes et. al.,2001)

The "Olympic pottery puzzle", is another interactive program that targets children and allows them to reconstruct ancient vases by moving virtual parts and combining them together (See Figure 3.22) (Gaitatzes et al., 2001).

The non-photorealistic representation of these heritage sites, as well as creating the possibility of interaction, provides flexibility, which in return affects the interpretation of the site. These examples do not, however, directly provide the user with various interpretations or offer different scenarios.

One of the tools used to allow different interpretations is enabling users to change views and navigate within the reconstructed model and even to manipulate the objects. This kind of manipulation allows alternative interpretations for the same model. Kensek et al. (2004) is one of the few research works to focus on representing the uncertainty of archaeological reconstructions through interactivity. It provides the user with quantitative data regarding the degree of reliability of the different sections of the reconstructed model. It also clearly addresses the issue of data transparency as it enables the user to access meta data related to the reconstructed model. As the key research study in this area, it is discussed in greater detail below. Other research that focuses on presenting multiple interpretations includes work by Farazis et al. (2019). Their research centres on public outreach, with special focus on the issue of the limitations of interactivity in the preservation of antiquities, and examines how digital technologies could allow further interactivity, creating the possibility of integrating intangible media within models to provide various interpretations and approaches. The virtual reality model shown in Figure 3.24 is a photorealistic rendered model with interactive points that provide further historical textual and visual information (Farazis et al., 2019). However, as in other work involving photorealistic models, the research does not discuss uncertainty directly.

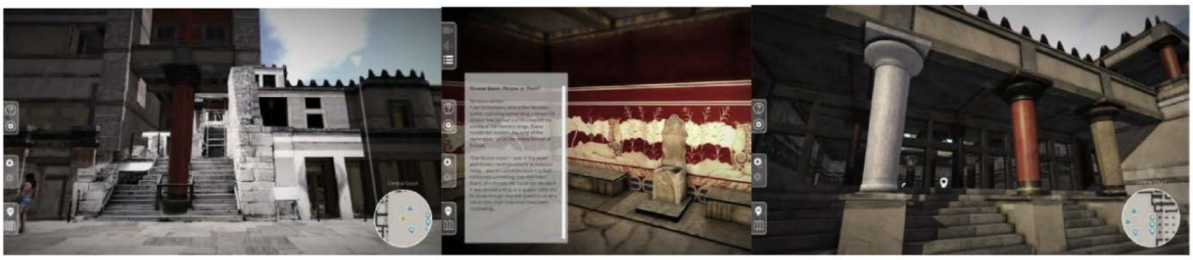


Figure 3.26: Interactive points in the 3D environment.
Source: Farazis et al., (2019)

By contrast, Kensek et al. (2004) developed two interactive prototypes that integrate different types of evidence within virtual reconstructions. Both prototypes facilitate the perception of multiple evidence, both independently and in interrelation through virtual reconstruction. The first prototype allows multimedia components to be linked to the virtual reconstruction, including further information about the level of confidence of each component in the model. This is clarified for the user by providing further information about the site. This includes details about existing ruins, structural feasibility, textual sources, ancient and modern pictures, comparative examples (appropriate cultural norms), and alternatives offered by other researchers. As the user requests further information, it is provided using a number of different techniques, including sound, text, scanned photographs, other reconstructions (Kensek et al., 2004). The main contribution of this first prototype is using bar graphs to graphically present the evidentiary basis for various choices. This allows the users to move from the view of the reconstruction to the rationale behind it. As the images in Figures 3.25 and 3.26 illustrate, the user can access various reconstructed views and tabs that provide geographic, historic, textual and archival data related to the site. This example is considered very comprehensive as it covers a number of the recommendations made in the charters in one console.

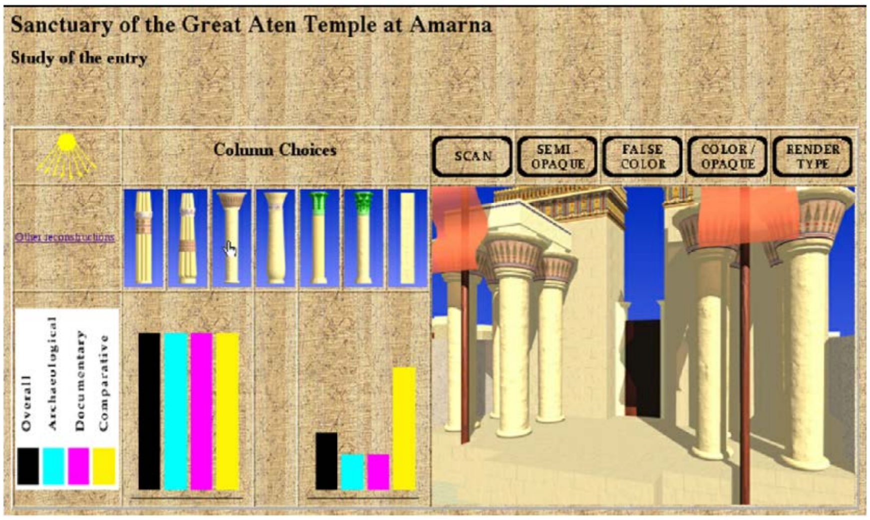


Figure 3.27: The console can be used to cycle through various reconstructed views. It uses bar graphs to graphically present the evidentiary basis for the various choices.Source: Kensek et. al. (2014)

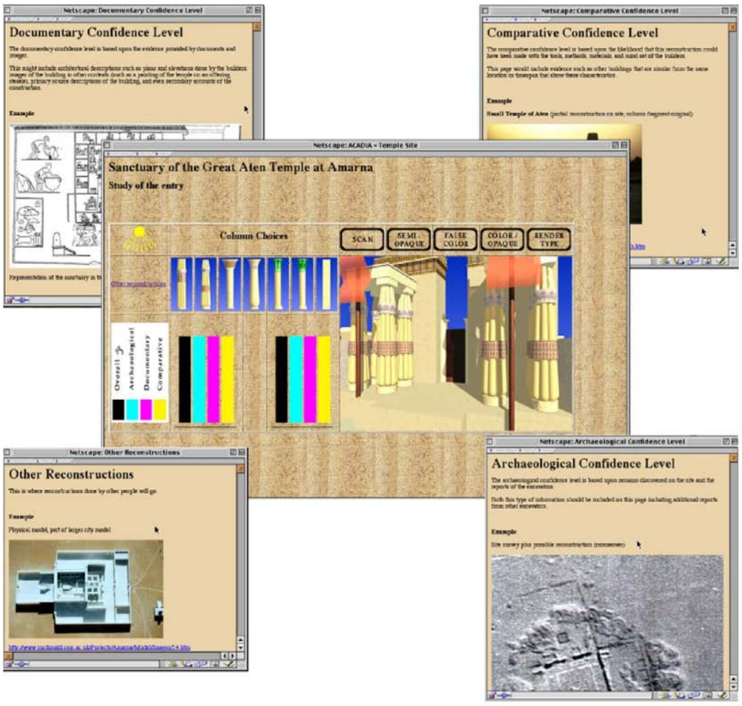


Figure 3.28: Pop-up windows appear when any of the evidence bar graphs are clicked and allow access to a discursive narrative about the evidence (composite image). Source:Kensek et. al. (2014)

The second prototype allows different reconstructions of Egyptian columns to be generated by combining different shafts, bases, and capitals (See Figures 3.27 and 3.28). These represent different alternatives for visualizing the uncertainty of the digital reconstructions which in turn prevents false interpretations. This prototype allows the user to remain in the virtual reality environment while accessing more information about the reconstruction and the level of confidence of the different combinations of columns (Kensek et al., 2004). As the figures illustrate, the user can click on a column within the virtual reality environment and a pop-up window appears; this provides further data, including the degree of reliability of this combination of capital, shaft and base for the column. It also enables the user to select alternatives for each different part of the column to create their own column. The user is then provided with information regarding the different degrees of reliability of their combination, based on archaeological, documentary or comparative evidence. The rendering style in this example was a simplified non-realistic rendering.

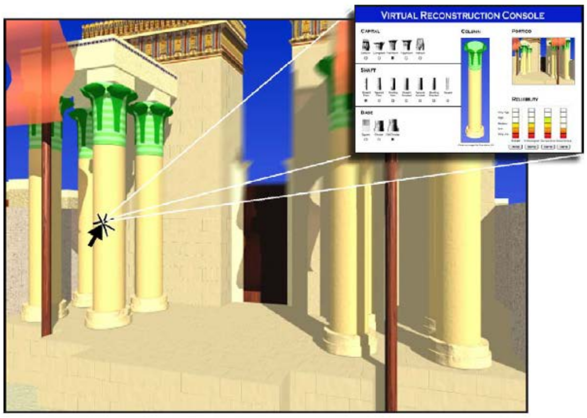


Figure 3.29: An area of the virtual reconstruction can be used to link to a pop-up window that gives information about the level of confidence in this element of the reconstruction. Source: Kensek et. al. (2014)

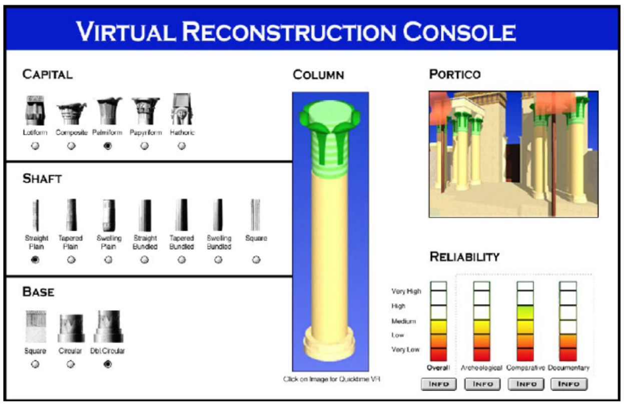


Figure 3.30: Detail of the console that allows multiple components of a particular element in the reconstruction to vary (prototype mockup) Source: Kensek et. al. (2014)

Roussou and Drettakis (2003) also discuss the necessity of enhancing the perception of realism and how this could be achieved through both photorealistic and non-photorealistic renders while adding interactivity. They developed a prototype of interactive virtual reality experiences which was applied to the Tholos monument of the Argos Agora. The prototype provides an interactive virtual reality environment where users can alternate between two different interpretations of the Tholos monument (Roussou and Drettakis, 2003). These are shown in Figure 3.31.

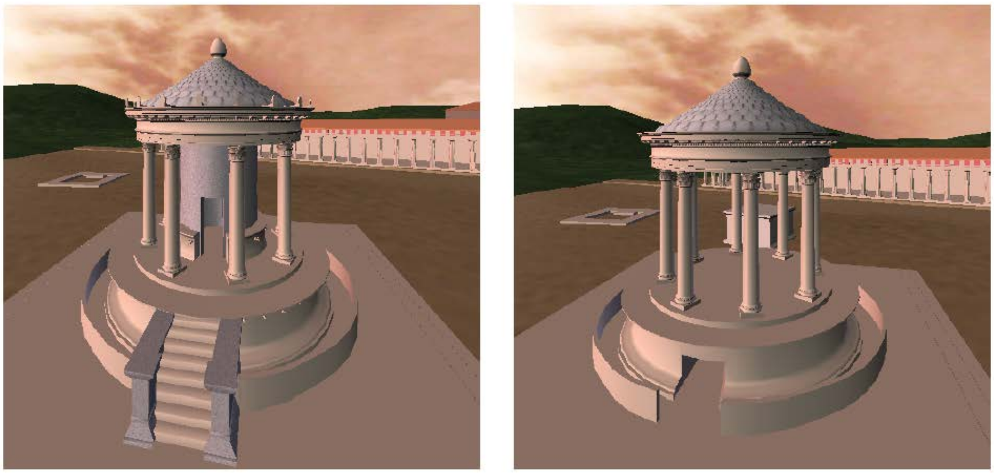


Figure 3.31: Two different hypotheses for the Tholos monument. Left, the hypothesis of P. Marchetti, and right the hypothesis of M. Pierart. The images presented are snapshots of the VR system. The user can switch between representations interactively. Source: Roussou and Drettakis (2003).

Providing alternative reconstructions of the same archaeological site follows the recommendations in the charters to provide alternatives in order to address the uncertainty and transparency of the interpretation. However, users are not provided with meta data that supports these interpretations. The rationale and the basis for each reconstruction is not clear to the user and they cannot tell which sources of data were used or what process was followed in the reconstruction. As discussed above, this approach could be best for addressing the general public, as it is simple to understand and easy to navigate from one interpretation to the other. The rendering technique in this case study is photorealistic, in contrast to the previous case by Kensek et al., and this would also be recommended when the target is the general public.

Roussou and Drettakis also proposed another prototype which allows further interactivity. In the second prototype, the user is allowed to manipulate architectural fragments within the virtual environment to recreate the monuments (Roussou and Drettakis, 2003) (See Figure 3.32). The process of recreating the archaeological site in this way supports the aspect of subjectivity by encouraging the user to comprehend that this reconstruction is based on fragmented evidence that was found on site, or elsewhere. However, although this research work presents two different alternatives for integrating interactivity that provide multiple interpretations, it does not assess how this affects users' perceptions.

Figure 3.32: The monument as fragments (Left) and with the fragments placed in their correct positions (Right)
Source: Roussou and Drettakis (2003)

3.8 A Framework to Represent Uncertainty in Digital Archaeological Reconstructions

Through exploring these case studies, it is clear that this field of research is still novel, and many of the recommendations made in the charters and theoretical studies have yet to be tested. While some research has been conducted regarding the representation of uncertainty in the modelling and rendering of the models, there is minimal research on interactivity and there appears to be no research work examining the impact of immersion on the user. Research work has also focused on the case studies at only one point in time, with no studies of the uncertainty of digital archaeological reconstructions in a 4D diachronic model. This is a significant omission because archaeological sites normally go through various phases over time and, in many cases, include remains from different historic eras, and the complexity this creates contributes to the uncertainty associated with them. However, virtual reality can act as a medium to explore changes over time, presenting sites in four dimensions, and integrating the meta data available for each historical periods. In addition, there are no existing theoretical frameworks that discuss the representation of uncertainty within virtual reality environments, taking modelling, interactivity and immersion into consideration. The fact of being present within the environment itself has a huge impact on the realization of those visualizations, and this, in turn, has an impact on the perception of the uncertainty of virtual archaeological reconstructions. Therefore, as virtual reality environments have a different nature than other computer-based visualizations, a theoretical framework for discussing how uncertainty could be reflected within them is important.

Throughout this chapter, a framework for theorizing the uncertainty of digital archaeological reconstructions has been developed based on the literature review. This began by taking the definition of uncertainty as a theoretical concept and the different classifications of uncertainty and applying them to the field of virtual archaeology (See Figure 3.3). This was done firstly by creating a flow chart for the different types of data involved and their manifestation through the virtual reconstruction of archaeological sites (See Figure 3.2). A matrix for the characteristics of these data sources was then developed that determines the type of source, the source completeness, the source reliability, and the level of interpretation (See Figure 3.4). The final element is the flow chart presented in Figure 3.33 which provides a framework for representing the uncertainty of archaeological reconstructions in virtual reality models. Together they form the major contribution to knowledge of this part of the thesis.

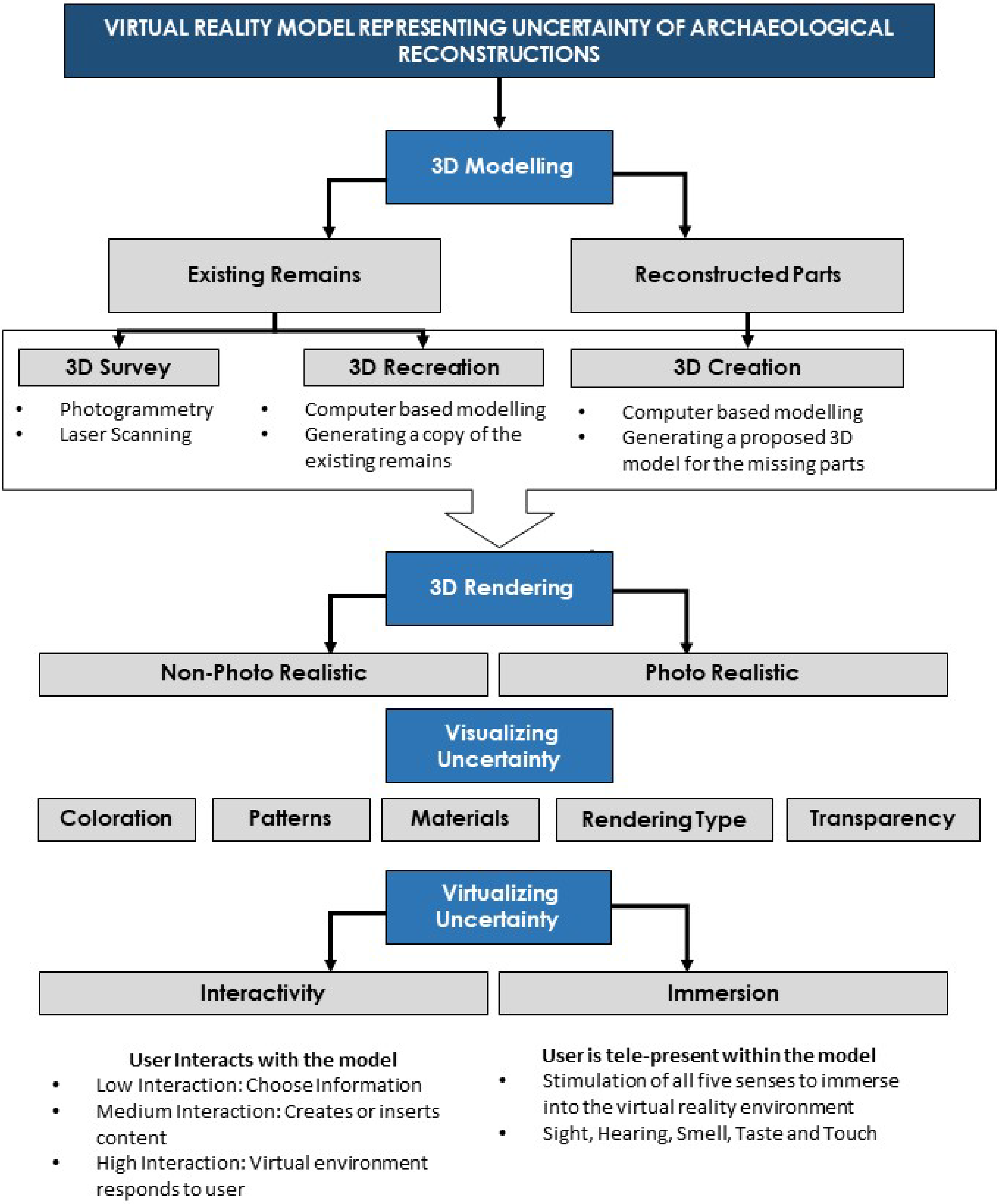


Figure 3.33: Framework for Representing Uncertainty of Archaeological Reconstruction in Virtual Reality Models.
Source: Created by the Author

3.9 Conclusion

In conclusion, uncertainty is an important aspect that needs to be taken into consideration in the virtual reconstruction of archaeological sites. However, there is no specific definition or single type of uncertainty; it is multifaceted, and multiple factors contribute to the uncertainty within the interpretation of archaeological evidence. Uncertainty can be subjective or objective, and it can be minimized but never eliminated entirely. Uncertainty arises from both the uncertainty of data and uncertainty about the interpretation of data.

Uncertainty in the context of this research can thus be defined as "The multiplicity of possible reconstructions for the same archaeological site that occurs due to two main factors. Firstly, imprecise, incomplete and inconsistent evidence and data. Secondly, the subjectivity of interpretation by various experts.

As digital archaeological reconstructions are based on different sources of data, and each project will include different sets of data, it is important to be clear about the different types (Input data, Para Data, Output Data and Meta Data) and to deal with each of them according to the recommendations made in the charters and principles.

While it is important to take these recommendations into consideration, especially when using computer-based reconstructions of archaeological sites, it can be difficult to take account of all of them within one project. This may be because they do not necessarily apply to each project, but also because this can be a very complicated process. It is, however, concluded that, as long as uncertainty is addressed in some regard, this will clarify that the proposed reconstruction is to a certain extent "hypothetical". This chapter has contributed towards addressing the uncertainty in the context of digital archaeology by providing a:

- Classification of the factors contributing to the uncertainty in digital archaeological reconstructions;
- Theoretical framework addressing the representation of uncertainty within virtual reality environments, including modelling, interaction and immersion;
- Methodological approach for representing uncertainty in a 4D diachronic model for an archaeological site

4. CHAPTER 4: RESEARCH METHODOLOGY

4.1 Introduction

This chapter presents the research methodology adopted in this thesis and provides an explanation for the data gathering and data analysis methods used in the different sections of this research. Throughout the research process, it is essential to identify an appropriate theoretical perspective and to adopt suitable research methods and methodologies to ensure the research aim and questions are achieved, and to do so with academic rigour. Through this chapter, the philosophical position of the research and the rationale for the methodology, the research design and the methodology implementation are detailed and justified.

The methodology of a research is the procedure through which the choice and use of a number of methods is made in order to reach the research aims in a scientific manner. The methodology is the process of doing the research and relates to the research methods selected and the philosophical position of the research. Commonly adopted research methods include interview research, quantitative surveys, and case study research, while the philosophical position determines the purpose of the research and the philosophy behind it in relation to the world and the different research paradigms. This means that the methodology is the rationale behind choosing different methods that best serve the research aim and outcomes (Byrne, 2017b).

Methodologies fall within the main two types of science: ontology and epistemology. Ontology is a Greek term which could be translated as "Science of being" (Simons, 2015). Historically, ontology is known to be focused on the concept of realism (Hathcoat et al., 2019). In general, a realist believes "that entities exist independently of being perceived, or independently of our theories about them" (Phillips, 1987, p. 205). In the social sciences, ontology, in the view of a realist, will mean that the phenomenon under investigation exists as an entity irrespective of our input as researchers (Hathcoat et al., 2019). Epistemology, on the other hand, is a branch of philosophical research that focuses on the nature, limitations, and justifications of human knowledge. What is knowledge? What is the relation between the knower and the known? How are the knowledge claims justified? The range of possibilities when looking at phenomenon from this point of view is very wide, and the scope includes multiple positions when taking such questions into account (Hathcoat et al., 2019).

It is, therefore, the aim of this methodology chapter to clarify the *methods* that are proposed to be used and the *methodology* that guides the choice and use of those methods. What is the *theoretical perspective* that drives the methodology, and what is the *epistemology* that feeds in the theoretical perspective? Those four main elements of the research process could thus be defined as follows;

Epistemology: The theory of knowledge embedded in the theoretical perspective thus reflected in the methodology (Crotty, 2003, p. 3);

Theoretical Perspective: the philosophical position that defines the methodology, which in turn creates the context within which the research process falls, and which provides the basis for the logic and criteria of the research;

Methodology: the strategy, plan of action, and process of design lying behind the choice and use of particular methods and linking the choice and use of methods to the desired outcome;

Methods: the procedures followed by a researcher to gather and analyse data relevant to a specific research question.

One of the mostly widely used frameworks for research design is that created by Crotty (2010) which demonstrates how any research should first start by determining the epistemology behind it (See Figure 4.1). This is followed by focusing on the philosophical position, which then informs the choice of methodology. The methodology then provides a set of principles to guide the research strategy, and the research methods can then be determined in order to provide practical procedures to collect and design data. This framework acts as the main guide for explaining the research methodology in this chapter.

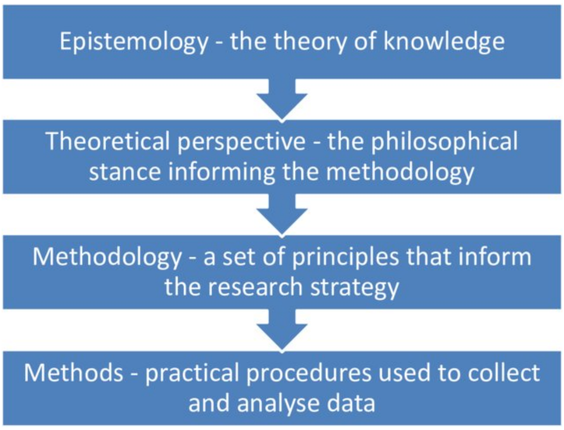


Figure 4.1: Diagrammatic summary of the research framework proposed by Crotty (2010)
Source: Allam & Alison (2015).

4.2 Philosophical Position of the Research

In order to determine the philosophical position of the research, it is important to identify the two main philosophical positions or paradigms that construct social science research: positivism and interpretivism. Positivist social sciences adopt concepts from the study of natural sciences to better understand societies, and this is reflected in the use of quantitative research methods in order to test hypotheses. Interpretivist (or anti positivist) social scientists, on the other hand, believe that there is a major difference between natural and social sciences, so it is inappropriate to use methods of natural science research in social science research. This means that in order to study social phenomena one has to study social worlds as people interpret them. In order to achieve this, interpretivists most commonly use qualitative research methods, such as open ended interviews, case study research, or ethnographic fieldwork (Byrne, 2017b).

Table 2 provides some examples following Crotty's (2003) framework. It shows the different epistemological positions and how they are reflected in the theoretical perspectives or philosophical positions. This is followed by examples of the methodologies and methods typically chosen within each epistemology.

Table 2: Examples within Crotty's Knowledge Framework (2003)
Source: Feast & Melles (2010).

Epistemology	Theoretical perspective	Methodology	Methods
Objectivism	Positivism Post-positivism	Experimental research Survey research Etc.	Sampling Measurement and scaling Statistical analysis Questionnaire Focus group Interview Etc.
Constructionism	Interpretivism • Symbolic interactionism • Phenomenology • Hermeneutics Critical Inquiry Feminism	Ethnography Grounded theory Phenomenological research Heuristic inquiry Action research Discourse analysis Feminist standpoint research Etc.	Qualitative interview Observation • Participant • Non-participant Case study Life history Narrative Theme identification Etc.
Subjectivism	Postmodernism Structuralism Post-stucturalism	Discourse theory Archaeology Genealogy Deconstruction Etc.	Autoethnography Semiotics Literary analysis Pastiche Intertextuality Etc.

As this research work is focused on exploring the subjective uncertainty of digital archaeological reconstructions it is evident that the main philosophical positioning lies within constructivism as an epistemology. The research focuses on analysing both experts' perceptions and interpretations of archaeological evidence and how this is presented in the reconstructions they create for lost archaeological sites. This approach is highly interpretive and mainly focuses on the subjective nature of the science of archaeology. The research also focuses on presenting different realities for the same archaeological site, based on different interpretations by different experts; so, even within the virtual reality experience application, the research follows the same philosophical position. In the final phase of testing the virtual reality experience with different users, the evaluation is done in the form of a relative scale in order to manifest the relativity of their understanding and the perception. Constructivism is often associated with qualitative research. The constructivist approach supports the fact that individuals develop subjective meanings based on their own experiences directed towards certain objects or things. These meanings are varied and multiple, leading the researcher to look for the complexity of views rather than narrowing meanings into a few categories or ideas. In such cases, the research is highly dependent on the participants' opinion of the phenomena being studied in order to achieve its main aims (Creswell & Creswell, 2014). The following section explains how this theoretical position was translated into a methodological process in order to achieve the aims of this research study.

4.3 Methodology Rationale

As previously mentioned, a constructivist view point typically draws on qualitative methods, and the research undertaken here follows a set of qualitative research methods. This is mainly due to the nature of the research and the fact that it follows a constructivist approach. The subjective nature of the study made the choice of qualitative methods most suitable to reach the intended outcomes. In the context of this research, qualitative methods enable the following actions:

- To collect meanings from participants related to their own perception and understanding (Creswell & Creswell, 2014). For example, this is achieved through conducting one to one interviews with experts to understand the process they undertake in order to reach an interpretation of an archaeological site;
- To study the context or settings that determine the occurrence of a certain phenomenon, based on the participants involved (Creswell & Creswell, 2014). This is evident, for example, in exploring different interpretations of the same archaeological site, both within the literature and within the applied case study. The exploration of the context within which the interpretation is generated is highly qualitative in nature.

- To focus on a specific concept or phenomenon (Creswell & Creswell, 2014). This is achieved through focusing on the subjective uncertainty of digital archaeological reconstructions. This is also evident in choosing a single case study approach, which is one of the most common approaches in qualitative research.

The following table shows the main epistemological and theoretical positions, the methodologies associated with them, and whether they were adopted in this research (See Table 3). It also details the research methods used. One to one interviews, case study research, and observations are considered as qualitative data gathering methods. The Likert scale survey may be considered quantitative in principle, as it collects numerical data; however, it also gives qualitative indications as it provides a relative evaluation of participants' opinions (Creswell & Creswell, 2014). The reasons for choosing each of these methods are explained in the following sections.

Table 3: Paradigm, Methodology and Methods Selected for the Research

Paradigm	Adopted in this research	Methodology Selected
Objectivism Positivism/Post Positivism	No	Quantitative
Constructivism Interpretivism	Yes	Qualitative One to One Interview Case Study Observation Likert Scale Survey
Subjectivism Post-modernism, Structuralism, Post Structuralism	No	Qualitative

4.4 Research Design

Having identified the philosophical position of the research and provided a rationale for the main methodological approach selected, this section explains the research design and the methods chosen to achieve each research objective. The study follows an exploratory research design. Exploratory research focuses on identifying a problem then clarifying concepts to generate a hypothesis which is then evaluated for the sake of advancing future research (Voxco, 2021). Data gathered in exploratory research is generally qualitative, and research participants are normally chosen for their knowledge and understanding about the research topic. Exploratory research might start, for example, by exploring the literature or a case study or a focus group discussion, and common methods for data gathering include brain storming sessions, interviews with experts, focus groups or observations (Sue & Ritter, 2007, p. 3).

Exploratory research is normally used to explore a research problem that is not clearly defined, especially when a topic needs to be examined in depth as it hasn't been widely explored before (QuestionPro, 2021). In this case, the literature related to the research work in question was found to be very limited as this research is exploring the possibility of presenting the subjectivity of digital archaeological reconstructions which is a very much underexplored topic. As a result, this study is considered to be exploratory research, using a variety of methods. Figure 4.2 illustrates the exploratory research design adopted for this study.

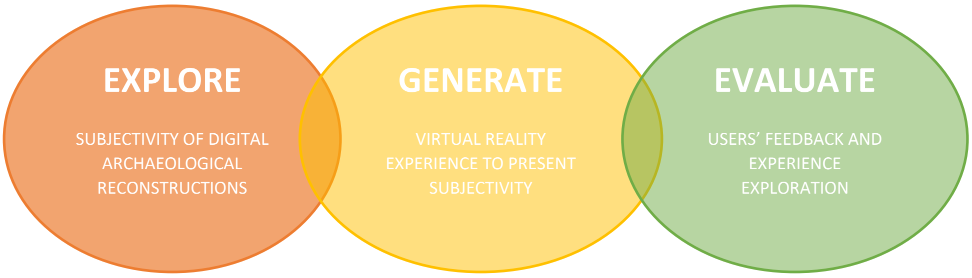


Figure 4.2: Research Design through an exploratory approach
Source: https://www.questionpro.com/blog/exploratory-research/

4.5 Methodology Implementation

The following section explains the different phases of the research and the data gathering and data analysis methods in detail. The methodology was implemented in five main phases. Phase One was the literature review, and this led to the development of the theoretical framework in Phase Two. This in turn was used to generate a set of questions to put to the experts in the field in the next phase. Phase Three included the interviews which targeted experts involved in the digital reconstruction of lost archaeological sites and which served to generate a better understanding of how the uncertainty of digital archaeological reconstructions is reached and represented. This phase was also used to validate the theoretical framework developed in Phase Two. Phase Four included a case study application in the form of generating a virtual reality experience, and Phase Five involved an evaluation of that virtual reality experience. These phases are illustrated in Table 4 and described in more detail in the following sections.

As explained above, the methodological approach adopted for the study is qualitative in nature, with an exception in the case of the Likert scale survey. The methods were selected as the most appropriate to achieve the research aims; some aims were achieved through the literature review while others were met through the applied parts of the research (See Table 5).

Table 4: Methodology Implementation

PHASE 1: LITERATURE REVIEW

- ARCHAEOLOGICAL THEORIES (DIGITAL ARCHAEOLOGY)
- VIRTUAL ARCHAEOLOGY
- UNCERTAINTY THEORY AND ITS IMPLICATIONS IN ARCHAEOLOGY

DATA GATHERING :	DATA ANALYSIS :
SECONDARY DATA COLLECTION EXISTING LITERATURE	INTEGRATIVE LITERATURE REVIEW (USED TO ESTABLISH A NEW THEORETICAL FRAMEWORK FOR NEW EMERGING TOPICS)

ELEMENTS THAT CONSTITUTE THE UNCERTAINTY OF DIGITAL RECONSTRUCTION

PHASE 2: THEORETICAL FRAMEWORK

- VIRTUALIZING THE UNCERTAINTY OF DIGITAL ARCHAEOLOGICAL RECONSTRUCTIONS
- SIMILAR EXAMPLES AND APPLICATIONS

DATA GATHERING :	DATA ANALYSIS :
SECONDARY DATA COLLECTION EXISTING LITERATURE	INTEGRATIVE LITERATURE REVIEW (USED TO ESTABLISH A NEW THEORETICAL FRAMEWORK FOR NEW EMERGING TOPICS)

THEORETICAL FRAMEWORK FOR REPRESENTING UNCERTAINTY IN DIGITAL RECONSTRUCTIONS

PHASE 3: VALIDATION OF THEORETICAL FRAMEWORK
ONE TO ONE INTERVIEWS

- HOW DO EXPERTS CONTRIBUTE TO THE UNCERTAINTY ?
- HOW DOES THE INTERPRETATION TAKE PLACE ? (INTERVIEW)
- IS UNCERTAINTY REPRESENTED ?
- HOW COULD UNCERTAINTY BE REPRESENTED IN DIGITAL RECONSTRUCTIONS?

DATA GATHERING :	DATA ANALYSIS :
STRUCTURED INTERVIEWING	COMPUTER ASSISTED ANALYSIS NVivo

METHODOLOGICAL APPROACH FOR VISUALISING UNCERTAINTY IN DIGITAL RECONSTRUCTIONS

PHASE 4: METHODOLOGICAL APPROACH APPLICATION
CASE STUDY RESEARCH HAWARA PYRAMID AND LABYRINTH OF EGYPT

- HAWARA IN BETWEEN VIRTUALITY AND REALITY
- TRACING THE UNCERTAINTY OF THE VIRTUAL RECONSTRUCTION OF THE EGYPTIAN LABYRINTH THROUGH HISTORY
- INVESTIGATING AVAILABLE DATA AND THE CURRENT STATE OF UNCERTAINTY INCLUDING ARCHAEOLOGICAL, HISTORIC, CONTEXTUAL DATA.
- DEVELOPING VIRTUAL REALITY EXPERIENCE

DATA GATHERING :	DATA ANALYSIS :
CASE STUDY DATA FIELD STUDY , DOCUMENTS AND RECORDS	FRAMEWORK ANALYSIS TO CLASSIFY EVIDENCE

PROTOTYPE OF VISUALIZING UNCERTAINTY IN DIGITAL RECONSTRUCTION (3D MODELS)

PHASE 5: USERS' FEEDBACK ON VIRTUAL REALITY EXPERIENCE

- EVALUATING THE INTERACTIVITY, IMMERSION, USER INTERFACE, EASE OF USE.
- EVALUATING THE VAILIDITY OF USING VIRTUAL REALITY IN THE FIELD OF DIGITAL ARCHAEOLOGICAL RECONSTRUCTIONS IN EGYPT AT MUSEUMS AND ARCHAEOLOGICAL SITES
- EVALUATING THE PRESENTATION OF THE UNCERTAINTY OF DIGITAL ARCHAEOLOGICAL RECONSTRUCTIONS IN VIRTUAL REALITY.

DATA GATHERING :	DATA ANALYSIS:
LIKERT SCALE SURVEY	STATISTICAL ANALYSIS

Table 5: Research Aims Achieved in the Phases of the Research Methodology

PHASE 1: LITERATURE REVIEW ,

RESEARCH AIMS ACHIEVED :

Exploring the possibility of representing different interpretations of history through the virtual reconstruction of historical and archaeological sites.

ELEMENTS THAT CONSTITUTE THE UNCERTAINTY OF DIGITAL RECONSTRUCTION

PHASE 2: THEORETICAL FRAMEWORK

RESEARCH AIMS ACHIEVED :

Developing a theoretical framework for the uncertainty of archaeological reconstructions

Identifying the degree of subjectivity of the different types of evidence used in the interpretation of the historical or archaeological sites and categorizing them from the least subjective to the most subjective.

THEORETICAL FRAMEWORK FOR REPRESENTING UNCERTAINTY IN DIGITAL RECONSTRUCTIONS

PHASE 3: VALIDATION OF THEORETICAL FRAMEWORK ONE TO ONE INTERVIEWS

RESEARCH AIMS ACHIEVED :

- Exploring the possibility of representing different interpretations of history through the virtual reconstruction of historical and archaeological sites.
- Differentiating between the evidence based data and the speculative data used in the interpretation of the historical and archaeological sites.
- Identifying the degree of subjectivity of the different types of evidence used in the interpretation of the historical or archaeological sites and categorizing them from the least subjective to the most subjective.

METHODOLOGICAL APPROACH FOR VISUALISING UNCERTAINTY IN DIGITAL RECONSTRUCTIONS

PHASE 4: METHODOLOGICAL APPROACH APPLICATION CASE STUDY RESEARCH HAWARA PYRAMID AND LABYRINTH OF EGYPT

RESEARCH AIMS ACHIEVED :

- Developing a methodological framework for representing the uncertainty of archaeological reconstructions in virtual reality models based on literature review and experts' validation
- Exploring the possibility of representing different interpretations of history through the virtual reconstruction of historical and archaeological sites.

PROTOTYPE OF VISUALIZING UNCERTAINTY IN DIGITAL RECONSTRUCTION (3D MODELS)

PHASE 5: USERS' FEEDBACK ON VIRTUAL REALITY EXPERIENCE

RESEARCH AIMS ACHIEVED :

Testing the methodological framework for representing the uncertainty of archaeological reconstructions by applying it on the Hawara labyrinth and pyramid case study.

4.5.1 Phase 1: Literature Review

After defining the research problem, research aim and objectives, the first phase of the research comprised a systematic literature review. The literature review presented here is divided into two sections: the first reviewing existing literature on digital archaeology, virtual archaeology and integrated modelling, and the second focused on theorizing the uncertainty of digital archaeological reconstructions. The first section focuses on exploring recent research using virtual reality in digital archaeological reconstructions, and it discusses digital archaeology from a general theoretical perspective and in relation to the current paradigm in archaeological thinking. This section highlights the ongoing debate about digital archaeology, both as a theory and as a method. This is important because, within this research, virtual archaeology is explored not merely as a tool but rather as an agent in changing archaeological theories, which will have an impact on the future of archaeology and its interpretation.

The first section of the literature review also examines the application of virtual archaeology in order to determine the scope and limitations of the research. It was important to consider different applications and target users in order to determine the gaps in current knowledge and identify how this research could be used in applications in the future. The research focuses on representing the uncertainty of digital archaeological reconstructions to the public with the aim of preventing the public being misinformed about archaeological sites, especially where few physical remains exist. The primary target users are, therefore, the general public; however, the theoretical framework and prototype model developed in this study are intended to be used by researchers and experts.

The literature review also explores integrated modelling as a tool for integrating different sets of data within digital archaeological reconstructions. Rather than discussing specific technologies and software, as technologies change and develop over time, the aim here is to develop a theoretical understanding of how using virtual reality as a technology impacts our interpretation and understanding of archaeological sites. Thus, while current technologies are explored through recent case studies in order to determine the most suitable approaches for this research, the study does not include all the technologies and software used in the digital documentation and reconstruction of archaeological sites. It is rather focused on the general approaches that are implied by their use.

4.5.1.1 *Data Gathering*

The data gathering in this phase depended on secondary data collection through exploring existing literature. The literature explored included mainly recently published books and journal articles in the field of digital archaeology. Data gathering here was thus dependent on secondary resources, meaning the data had originally been presented in another source (Northcentral University Library, 2021).

4.5.1.2 Data Analysis

The literature review analysis was conducted as an integrative literature review study. This approach was selected as it is considered to be the most suitable for establishing new theoretical frameworks for new emerging topics (Torraco, 2016).

4.5.2 Phase 2: Theoretical Framework

The review of existing literature on the uncertainty of digital archaeological reconstructions conducted in Phase One revealed that resources on the topic were very limited. Most of the research conducted focuses on the case studies involved, without generating general theoretical frameworks which included the various case studies and methodologies. This was the reason for conducting an integrative literature review rather than reviewing existing theoretical frameworks. The role that virtual reality as a technology could play in the representation of uncertainty is digital archaeological reconstructions has also never been explored extensively. As the uncertainty of digital archaeological reconstructions is a relatively under explored topic, the integrative literature review approach was used.

Data analysis using this approach is based on critically analyzing and examining existing literature and the main ideas and relationships relating to an issue. Taking this approach, the literature review was based on studying the concept of uncertainty as a general theory and exploring associated definitions that are relevant to uncertainty. The theoretical study of uncertainty therefore included a critical study of several definitions and classifications of uncertainty. These were then classified and applied to digital archaeological reconstructions in order to reflect how uncertainty arises within the reconstruction process.

The second phase of generating the theoretical framework involved exploring how uncertainty could be visualized and virtualized using virtual reality. A framework for virtualizing uncertainty is developed by exploring several case studies, as well as theoretical studies that involved the representation of digital archaeological reconstructions. The initial framework generated is validated in later phases of the research using one to one interviews with experts as well as by conducting a case study application. The case study application on a prototype model is also evaluated by end users.

4.5.2.1 Data Gathering

Data gathering in this phase depended on existing literature and mainly focused on recent journal articles and international charters and principles. Recent journal articles discussed projects involving the use of virtual reality in presenting reconstructed archaeological sites. International charters and principles discussed the recommendations and guidelines for using digital technologies in dealing with archaeological research and practice. This indicates the use of secondary data as a data gathering tool (Northcentral University Library, 2021).

4.5.2.2 Data Analysis

As explained above, analysis was conducted as an integrative literature review study. This approach was selected as it is for establishing new theoretical frameworks for new emerging topics (Torraco, 2016).

4.5.3 Phase 3: Validation of Theoretical Framework - Expert Interviews

This phase focuses on exploring the subjective uncertainty in digital archaeological reconstructions. It also explores the various factors that lead to differences in interpretations done by experts in order to generate digital reconstructions. It covers the use of digital archaeology as a medium for representing the uncertainty in archaeological reconstructions. This is achieved by exploring the following questions: Is it valid to question archaeological interpretations? To what extent are archaeological interpretations subjective? How much does an expert's background and knowledge impact the degree of uncertainty? How could subjective uncertainty be represented in archaeological reconstructions? Does virtual reality offer new possibilities for representing subjective uncertainty in archaeological reconstructions?

In order to address these points, interviews were conducted with several experts in the field of cultural heritage and archaeological reconstructions. These were drawn from various socio, cultural, and educational backgrounds, with the limitation that only experts who had previously been involved in archaeological interpretations and reconstruction of heritage sites were chosen.

4.5.3.1 Data Gathering

The data gathering was conducted through one to one interview. This data gathering method was chosen in opposition to surveys as the aim is to study the subjectivity of archaeological interpretations. One to one interviews are considered more suitable for qualitative research that targets certain participants with the aim of understanding their motivation into making certain decisions, so, as this phase aims to explore how experts interpret archaeological data and how this results in subjective uncertainty, one to one interviews were used. These were conducted through computer assisted personal interviewing (CAPI) as this was the most suitable method to conduct the interviews with the experts from different parts of the world. CAPI is a method of face to face interviews where the interviewer and the respondent meet through a computer to administer the questionnaire and to record the answers (SAGE Research Methods, 2021a).

4.5.3.2 Data Analysis

Data analysis in this phase was done via computer assisted data analysis using NVivo software. NVivo is widely used by qualitative researchers, and it provides a number of tools for managing data, ideas, information and theories, which are typically built up from observations, interviews, literature reviews, or other qualitative research processes (Salkind, 2010). This is the main reason why it was selected to be used for managing the data from the one to one interviews with the experts. Data analysis of the interviews was conducted using thematic content analysis, the most commonly used method for analyzing qualitative data, which is based on examining the data in order to identify common themes, topics, ideas, and patterns of meaning. Thematic content analysis is typically used in research when the aim is to explore people's views, opinions, knowledge, experiences, or values from qualitative data. Thematic content analysis was chosen to analyze the interview data as the focus is on analyzing the subjectivity of archaeological reconstructions based on the experts' background and knowledge.

4.5.4 Phase 4: Case Study – Methodological Application

In order to assess and evaluate the feasibility of the theoretical framework a case study application was conducted. The methodological approach focused on representing subjective uncertainty by using virtual reality technologies, with the aim of creating a 4D diachronic prototype model representing several interpretations for the same archaeological site. The focus on representing the subjectivity of experts' interpretation to the public is a novel approach, and the use of the interactivity aspect within virtual reality to present the subjectivity of archaeological reconstructions and interpretations was studied in detail.

The first part of the case study research was conducting a historical and archaeological study of the site, the Hawara Pyramid and Labyrinth at Fayoum, Egypt. This phase involved gathering all the available resources related to the site, and led to the creation of two sets of data: one set includes previous reconstructions of the archaeological site and the other comprises physical archaeological evidence, as well as other supporting evidence. The previous attempts at reconstructing the archaeological site are visualized using integrated modelling in order to present various interpretations of the same site through history to the user, with the use of 4D diachronic modelling allowing the user to understand the subjective nature of the archaeological interpretations. The second set of data includes the modelling of currently existing remains using photogrammetry and the remodelling of missing sections using various visualization techniques to represent the uncertainty of the digital reconstruction.

For the 4D diachronic model, the modelling of each interpretation of the site was created using 3D max software. The models were then integrated using HBIM software, with the 4D diachronic modelling generated through HBIM and synchro 4D. The modelling of the existing remains was generated by photogrammetry modelling using Agisoft software, and 3D max software was used to combine the archaeological fragments and remodel the missing parts whenever possible. Documentation of the existing remains model is integrated within the 4D diachronic model in recognition that it too is just an interpretation of the archaeological site. This is done in order to highlight the concept of subjective uncertainty and to remind users that, even with the latest available technologies, any attempted archaeological reconstruction is still subjective. The final model is based on post processual archaeology theories and provides an interactive model that includes archaeological remains from the site.

4.5.4.1 Data Gathering

The data gathering included assembling all the available information related to the case study. Data were mostly collected from archives and documents, as well as during field work and site visits by the researcher. The data included all available evidence related to the history of the archaeological site of the Hawara Pyramid and Labyrinth, comprising both primary and secondary data sources (Formplus, 2021). Some primary data was collected by the researcher in the form of visual images taken on site, which were then converted into 3D models using photogrammetry.

4.5.4.2 Data Analysis

Analysis of the data followed the framework analysis, which is a qualitative method for analyzing data. This method is used to organize and structure research data with the aim of refining the researcher’s focus to identify notable themes (SAGE Research Methods, 2021b; Byrne, 2017a). The evidence collected regarding the pyramid and labyrinth was classified through the framework analysis to generate a better understanding of the site, to identify important types of evidence, and to select the types of evidence to be used in constructing the virtual reality experience.

4.5.5 Phase 5: Virtual Reality Experience - Users' Feedback

The final phase of the research involved an evaluation of the 4D diachronic model generated in Phase Four. In order to achieve this, users were invited to interact with the model in order to access further details about the archaeological fragments. Participants were selected at random and given a brief explanation of what the virtual reality experience involves, as well as an explanation of how to navigate within it. They were then allowed to try it for themselves; the researcher did not interfere once the trial was underway, except in cases where the user was not able to navigate within the experience. The participants were then asked to provide feedback on various aspects of the experience using a Likert scale, with an open ended question for comments, feedback and future recommendations at the end.

4.5.5.1 Sampling

The number of participants in the virtual reality experience evaluation was 52, with different educational backgrounds and age groups. The sampling for participants in the evaluation was a random sampling. Random sampling is a selection of a sample from a larger population such that every member has an equal chance of selection (Lavrakas, 2008; SAGE Research Methods, 2021c). Random sampling was chosen as the virtual reality experience is intended to target the general public, either in archaeological sites or museums. This is why there was no specific criteria for selection.

4.5.5.2 Data Gathering Method: Likert Scale Survey

The Likert scale is a research method which involves a 1 - 5, 1 - 7, or 1 - 9 scale used to measure respondents' agreement with various statements. In general, a Likert scale will include a statement and the scale follows for the respondent to evaluate the extent to which he or she agrees or disagrees with it. Respondents choose from a range of answers that typically include “strongly agree”, “agree”, “neutral”, “disagree” or “strongly disagree”. In order to ensure the respondents are evaluating statements carefully, it is important to include a reverse scoring on some of the questions. In that way, if the respondent replies positively to positive statements and negatively to negative statements this gives the researcher more confidence in the data (Jamieson, 2017).

In this study, a Likert scale was used to gather users' feedback on the virtual reality experience. The participants were asked to evaluate the experience in relation to a number of different criteria, and these are explained and discussed extensively in chapter eight which discusses the users feedback.

4.5.5.3 Data Analysis

The results of the Likert scale were analyzed statistically to give an insight into the opinion of the users regarding the virtual reality experience. The statistical analysis is presented in the form of bar charts showing the degree of agreement or disagreement with all the statements involved in the survey.

4.6 Conclusion

This chapter has focused on discussing the methodology of the research. It has provided an explanation for the philosophical position of the research which adopts an interpretive approach. The research is qualitative research in all the different sections, and it includes a range of research methods, including one to one interviews, case study, and surveys in the format of a Likert scale. The use of different research methods was essential in order to create a better understanding of the uncertainty of digital archaeological reconstructions and how it could be visualized in virtual reality.

As the research topic has not been extensively studied previously, and no comprehensive framework pre-existed this study, it was important to address several aspects, including the theoretical underpinning, the experts' point of views, and the views of general users. It was also essential to create a prototype virtual reality experience for testing with users. In order to achieve, this a in detail here, including the data gathering and analysis method used in each phase and the process followed to create and evaluate the virtual reality experience.

In order to reach decisions regarding the methodology, an extensive study of all possible research methods to be used in each phase was conducted. The following chapters explore the methods selected in further detail. Chapter 5 explains the interview process, including how the types of questions were chosen and how NVivo was used in order to reach conclusions that enhance the theoretical understanding of the subjective uncertainty of digital archaeological reconstructions. The case study is then explored in Chapters 6 and 7. The reasons for choosing the case study are explained as well as the selection of certain software for the development of the virtual reality experience. In Chapter 8 the virtual reality experience trial is analyzed using the Likert scale analysis, and an explanation of the survey design is provided to clarify the aim of the user survey.

5. CHAPTER 5: EXPERTS' VALIDATION OF THE UNCERTAINTY OF DIGITAL ARCHAEOLOGICAL RECONSTRUCTIONS

5.1 Introduction

The main purpose of this study is to investigate the subjectivity of archaeological and historic reconstructions and the role that digital technologies can have in virtualizing this uncertainty. The previous chapters have presented a theoretical investigation into the subjectivity of digital archaeological reconstructions and the ways virtual reality could be used to represent it. Drawing on previous literature and case studies, the focus of the investigation was on using virtual reality as a new technology in various applications to present different interpretations of the same archaeological site, as well as representing the degree of subjectivity of the interpretations created by the experts. In the course of the investigation, uncertainty related to the digital archaeological reconstruction was found to be classified into "objective uncertainty" that arises from "evidence and data" and "subjective uncertainty" that arises from "experts and interpretation". In order to validate these theoretical findings, interviews were conducted with a number of experts in the field. The interview was chosen as a data gathering method as it facilitates in-depth investigation into the process which experts undergo in the virtual reconstruction of archaeological sites.

This chapter describes the interview design and analysis. The first section explains how the interviews were conducted and details the questions that were asked. The subsequent sections include the analysis of the interview transcriptions. The analysis itself is divided into several parts: the first includes an analysis of the types of evidence used in digital reconstruction of archaeological sites through virtual reality or other technologies. This section compares the types of evidence in a hierarchal analysis according to how much each type was mentioned by the different experts in the interview. This provides an insight into how different projects require a different approach when dealing with evidence, and also how experts differ in their views. Some types of evidence were discussed by all experts, while others were considered as secondary or not as important, differences which are explored in detail in the chapter.

The second section of the analysis includes an investigation into the subjectivity of digital archaeological reconstructions. A hierarchy is generated to rank the different types of evidence in order of subjectivity, from the least to the most subjective, in the opinion of the experts. This hierarchy plays an important role in developing a theoretical framework to determine which types of evidence are considered more reliable later in the chapter. In addition to this, a study of the frequency of words related to subjectivity and uncertainty used in the interview is presented. This is useful in understanding how subjectivity occurs during the experts' interpretation processes. The words are then divided into sub categories and linked together to strengthen understanding of subjective uncertainty at a deeper level as a means of validating the theoretical findings.

5.2 Interview Design and Questions

The interviews conducted with the experts were divided into four main sections. The first focused on asking about the methodology and the types of evidence and data they use in the digital reconstruction of archaeological sites. It focused on discussion of the different types of evidence and data and how they are used by the different experts in order to determine similarities or differences. The questions in this section were designed to be open and not directed towards specific types of evidence in order to give the participants a chance to discuss their approaches without any specific focus.

The second section investigated the processes of interpretation of the archaeological evidence utilised by the experts in order to reach a consensus regarding digital archaeological reconstructions. The questions in this section focused on asking the experts about the possibility of different interpretations of the same evidence arising and whether they considered discussing those interpretations with other experts or not. This section aimed to develop a deeper understanding of the subjectivity of the interpretation of archaeological evidence.

The third section asked about each type of evidence separately in order to determine which types are considered to be more important from the point of view of the experts. The types of evidence included within this section were identified and classified according to the literature review. The opinions of the different experts on which types of evidence they use and how they use them are thoroughly explored and analysed at the end of the chapter.

The fourth section explored how digital technologies and virtual reality can offer the possibility of representing different interpretations of the same archaeological site. It included questions related to how digital technologies and virtual reality facilitate the integration of different data to provide further information about the site. It also discussed how virtual reality as a technology could be used to visualize the uncertainty of archaeological reconstructions. The suggestions made by the experts in this section are applied to the case study in subsequent sections.

The interviews with the experts were conducted online virtually. A number of images and a brief introduction were presented before each section in order to introduce the participant to the research context. The images that were used were based on previous research work in the field of digital archaeology.A reference for this is included in the literature review of this research. The questions were displayed on slides, alongside images from previous similar research work. The images were used in order to open the discussion and to orient the participants towards answering the questions within the designed framework. Copies of the slides used during the interviews are included within Appendix (A.1) . The interview started by explaining the aim of the study which is "to investigate the subjectivity of archaeological and historic reconstructions and the role that digital technologies can have in virtualizing this uncertainty". The participants were informed that the interview would take around 45 to 60 minutes. The interviews were recorded through Zoom video communications. Transcription of the interviews was done manually by the researcher in order to ensure the accuracy of the transcription. All interviews were conducted in English; therefore there was no need for any translation and the quotations below are taken directly from the experts.

5.3 Interview Participants

The interview participants were chosen according to specific criteria in order to be able to reach valid conclusions that could be used to develop the theoretical findings. The participants were all experts in the field of digital archaeological reconstructions, and from various socio cultural and educational backgrounds. They also come from different disciplines; either archaeologists, architects or art historians, as these are the three main disciplines where experts who work on such projects are found. While some projects also involve experts from fields such as geology, computer science, or engineering, the criteria here was based on choosing experts in the process of interpreting evidence and data in order to reach a consensus related to how historical buildings might have looked in earlier periods. The only absolute limitation was that the experts must have been actively involved in archaeological interpretations and the digital reconstruction of archaeological or historic sites. The experts selected for interview were as follows

- Prof. Ian Haynes, Professor of Archaeology at Newcastle University, Newcastle, UK;
- Jonathan Gration, Research Assistant and PhD Researcher in Art History at De Montfort University, Leicester, UK;
- Dr Amira Saddik Aly, Egyptologist and Researcher at Cultnat-bibliotheca, Alexandria, Egypt, and a Member of the Egyptian Heritage Rescue Foundation;
- Prof. Galal Ebada, Professor of Architecture and Urbanism and Director of the Historic Cairo Studies and Development Centre at the Faculty of Engineering, Ain Shams University, Cairo, Egypt;
- Alastair Rawlinson, Head of Digital Innovation and Learning at Historic Environment Scotland; and
- Dr. Lyn Wilson, Digital Documentation Manager at Historic Environment Scotland.

All of these participants have experience in digital archaeology and art history (The Egyptian Heritage Rescue Foundation, 2018; Historic Environment Scotland (HES), 2021; Haynes et al., 2020; Gration, 2014; ARCHNET, 2021). Most of these experts were interviewed individually, but Alastair Rawlinson and Lyn Wilson were interviewed together.

5.4 Types of Evidence

As part of the process of trying to understand the degree of subjectivity in digital archaeological reconstructions, the experts were asked about the different types of evidence they use and how they use them. The following section compares the different opinions of experts on the types of evidence they use, the degree of importance they attach to them, and how each type is used in different projects.

As mentioned above, the interviews were transcribed manually by the research by listening to the interview recordings. The transcriptions were then embedded within NVIVO software in order to be able to analyze qualitative data and convert it into quantitative data. The coding of the data included all the conversations with the experts, and the different types of evidence were coded in separate nodes to enable further analysis of each node. The nodes that were created through NVIVO software include *archaeological evidence*, *survey data*, *architectural evidence*, *artefacts in museum collections*, *textual evidence*, *visual evidence*, *similar architecture*, *functional evidence* and *environmental context*. Each node was presented as a percentage which reflects how long each expert discussed that type of evidence during their interview, something which varied considerably from expert to expert and from one project to another as the conversation developed. A hierarchy was then generated according to how much the experts discussed each type throughout the whole interview. The type of evidence mentioned most was archaeological remains on site while the least mentioned was architectural elements.

Figure 5.1 is a tree map generated through NVIVO, which indicates the weighting of each type of evidence according to how often it was mentioned by the experts.

Figure 5.1: Tree map of the types of evidence according to the degree of importance

As the figure illustrates, archaeological remains on site were mentioned most frequently, and they constitute the most important type of evidence used in the digital reconstruction of archaeological sites and also the most reliable source. The experts also spoke at length about artefacts in museum collections as well as textual evidence. The use of visual evidence, previous reconstructions, and contextual comparisons in a variety of projects was also mentioned. However, evidence such as using similar architecture as a reference, survey data from the site in its pure form (without further investigating it as archaeological evidence), and evidence related to the function of the building were not considered as important and were not discussed in detail by all the experts. This indicates that these types of indirect evidence are not the main sources that they look to during the interpretation process. The environmental context was also mentioned less, suggesting that evidence that is not directly related to the site or to archaeology is not generally relied on; however, it is sometimes used as complementary evidence.

Nonetheless, the experts stressed that the type of evidence changes from one project to another, as the quotations below illustrate:

> *"As for what one uses in terms of evidence as an archaeologist is a very, very big question. The obvious starting point when one's dealing with buildings is that one's looking for architectural elements and plans, and, where possible, preserved elevations. I think, first of all, the obvious [thing] is that one's looking for what remains of the original structure as much as possible, but one is also looking for much of the original landscape. These are buildings that are sat within the landscape, and where I think people get into significant difficulties is obviously in the higher levels of structural elevations and, particularly, in roofing materials which are very frequently paid less attention in practice by archaeologists than they should. […] In the Gandhara example, we checked all sorts of different sources."* (Ian Haynes)

As Ian Haynes explains, there is no single process when it comes to the type of evidence used in the digital reconstruction of archaeological sites. However, he makes clear that the first and most obvious type of evidence that any expert will consider is the actual remains on site. The other types of evidence might then be different from one site to another and from one project to another.

> *"First type of data is the remaining evidence on site, Case A if you have remains, Case B if you don't have remains. If you have remains, you will rely mainly on those remaining items, artefacts, or whatever; if not, we rely completely on other sources - textual, pictorial, drawings, places, comparisons sometimes, correlation with others, other similar buildings."* (Galal Ebada)

Galal Ebada also agrees that the first type of evidence used is actual remains on site. However, he points out that, with some reconstruction projects, it is sometimes the case that there are no actual remains on the site. In this instance, the other types of evidence are relied on, including textual and pictorial evidence, drawings, contextual comparisons, and even similar buildings. The process of identifying the types of evidence available is therefore an essential requirement before creating a reconstruction of an archaeological site as the types of data available will be an important aspect when developing the methodology.

Jonathan Gration, on the other hand, doesn't prioritize archaeological remains. He describes evidence as pieces of information and data, and he tries to gather as much as he can from different sources:

> *"My answer would be any type of data that you can get your hands on, any kind of capturing, measurements, laser scanning - that kind of data. Down to archaeological material, samples that you can take in order to reconstruct*

columns, things like that. Visual records - in my case, I tend to work in 17th and 18th century […], there might be drawings, there might be water colours, there might be photographs for the location I am working on. And then beyond those that are clearly linked to a site, I use also influences from similar sites elsewhere, so you might not know exactly the right material that was specifically used in this site or the specific element, but we might have a very similar building somewhere else or very similar interior somewhere else, and we would assume that they would've used wood for that element. I guess there is this aspect of contextual information about the typology that we are working on." (Jonathan Gration)

He also clarifies that the type of evidence changes according to the historic period; this means that certain periods would have drawings, for example, as a main reference, while others will depend more on archaeological finds. He also refers to evidence taken from other similar or surrounding sites as "contextual information", something which is discussed in detail later in the chapter. Meanwhile, Amira Saddik classifies the types of evidence used into large zone or large scale evidence and small zone or small scale evidence:

"The types of evidence include buildings, complexes, architectural elements and objects. In order to generate the reconstruction we have to go from the large zone into the small zone. The large zone is the archaeological site itself, including the components of the archaeological site. Some archaeological sites include different types of complexes or building plus separated buildings or some objects." (Amira Saddik)

This is a different approach for developing a digital archaeological reconstruction as it relies on moving from a large scale to a small scale rather than working with data depending on its availability. Large scale evidence includes material from the site itself, such as buildings, complexes, architectural elements, and objects, while small scale evidence includes artefacts, visual or textual evidence, and other archival sources. The following sections examine each of the main evidence types in more detail, beginning with archaeological remains on site.

5.4.1 Archaeological Remains On Site

Archaeological remains on site are probably the most important evidence in the reconstruction process according to all the experts that were interviewed. All of them discuss remains on site in detail, and it occupies a relatively large share of the discussion when compared with other types of evidence, as will be discussed later in this chapter. The bar chart in Figure 5.2 illustrates the extent to which each expert mentions archaeological evidence during their interview.

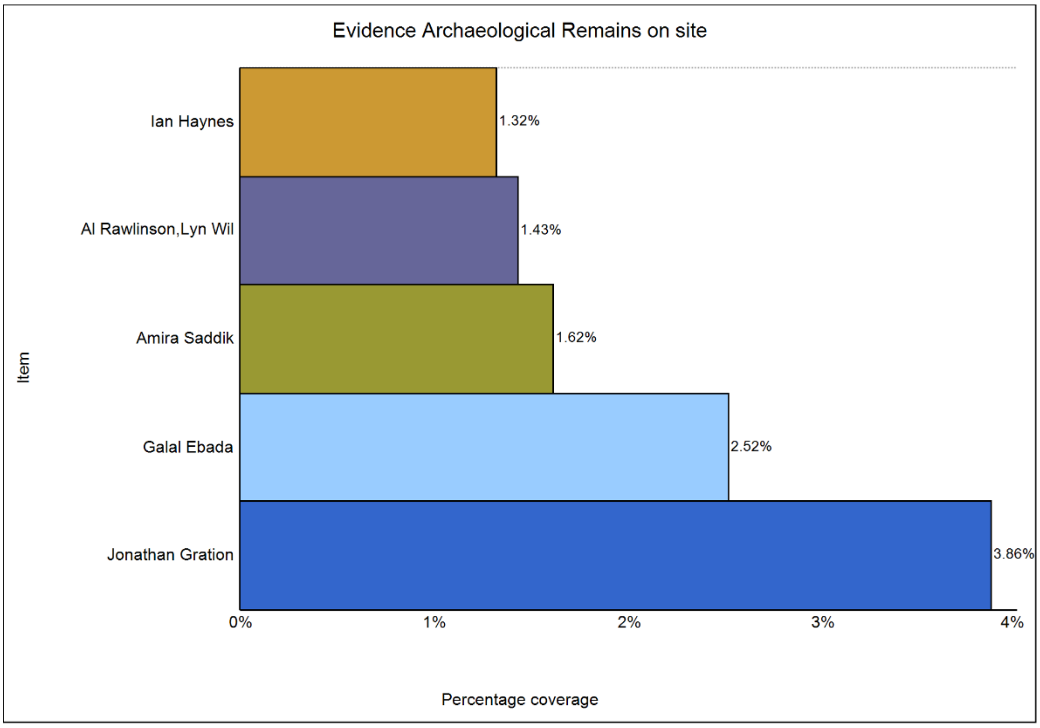


Figure 5.2: Bar chart for percentage coverage of archaeological remains on site during the expert interviews

Although Gration highlights the importance of contextual data, he also acknowledges the significance of remains on site. He explains that it is normally the first thing to refer to because it is the most reliable source of evidence as it is seldom manipulated or altered in any way. However it should be taken into consideration that evidence on site might've been brought from other sites, reconstructed at any given point in time or manipulated to change the narrative regarding the existing archaeological finds. This means it provides a strong starting point upon which to build; however, uncertainty can arise when the physical evidence on site is limited:

> *"I wouldn't say security, but it gives you a starting point, so it gives you something to start with, sometimes it's the only thing that you have. I don't know if it gives you security - it is the base for your model, and it gives you the scale. But then, if you have a Roman town as an archaeological site, you wouldn't know if it is one floor or two floors just by looking at the foundations, and so there is a lot of uncertainty that comes if you have those low structural evidence. However, in my case, I tend to be working with built heritage, so the walls and the ceiling are already there, so the structural evidence does give you a lot more information than with archaeological sites."* (Jonathan Gration)

As Gration points out, the foundations may be sufficient to understand the layout of a site, but, in many archaeological sites, the third dimension is missing. In some cases, parts of the walls, columns, roofs remain, and this gives the researcher more evidence to build from, as information from those remains can be duplicated to complete missing sections. However, foundations alone provide few indications about how the building looked, and this raises a high degree of uncertainty.

Haynes agrees that, although in situ evidence exists on site and plays an essential role, it is still insufficient to totally comprehend the design of the building. He explains that in order to be able to reconstruct a building it is important to be able to get information about its design and construction:

> *"So the thing is, even if I have in situ evidence, I've still got another problem, right, and the problem is facing one of the issues that I find very difficult in many cases. What I am interested in with a building is looking at the formative and initial phase of that structure."* (Ian Haynes)

This highlights the fact that the digital reconstruction of archaeological sites relies on both the interpretation of evidence and the understanding of the architectural styles of the historic period during which the building was constructed.

Ebada also discusses the importance of studying the structural evidence on site. For him, this provides the starting point in comprehending the architectural design of a building, and he stresses the need to find evidence related to the structural elements specifically:

> *"Structural evidence is very important in terms of architecture - we are looking for structural elements before the reconstruction process. In order to understand the structure, we have to study the structural system which is essential for reconstruction. In order to understand the design of the building it is important to study the structural system."* (Galal Ebada)

So, building on the previous comments by Haynes, it is important not only to study the architectural style and concept of the building but also the structural system. Each of these layers of evidence generates a deeper understanding of the available in situ evidence.

Saddik, by contrast, focuses on a specific type of archaeological evidence - the foundations found on site. For her, foundations are, in many cases, the starting point and the base for archaeological reconstructions:

> *"The foundation is the main reconstruction element that we have to look for, because this foundation is the main remain that we rebuild the construction on it.*

It is considered as the initial plan that you search for. This is the first resource that we search for." (Amira Saddik)

The foundations are one of the most reliable resources, mainly because they are in situ evidence that has not been removed from site. They also give specialists the basis for the layout of the site, which is considered the starting point for establishing plans and then 3D modelling. Identifying the foundations and studying the architectural style and structural system can provide a relatively reliable base for a 3D digital reconstruction; however, the possibility of alternatives still exists due to the incompleteness of evidence that necessitates a certain degree of interpretation.

According to Al Rawlinson and Lyn Wilson, there is also another type of archaeological remains on site that experts refer to, namely artefacts. For them, *"Artefacts are fundamental to archaeological reconstructions,"* as they represent *"the material cultural evidence"*. Architectural fragments may include parts of columns or walls, and they give examples of *"columns and capitals that were found on site,"* and *"seventeen or eighteen fragments which were scattered around different sections."* Architectural fragments are significant because they give indications of architectural styles as well as materials or engravings, and these kinds of details are important for adding the third dimension in 3D modelling. For example, if one column capital is found, it is then easy to replicate this around the whole site where there are foundations that indicate that columns existed. Also, artefacts found on site are more reliable, in some cases, than artefacts found in museums. The main reason for this is that there is no doubt that they have actually come from the site.

In summary, the comments by the different experts indicate that archaeological remains found on site can be divided to two types: firstly, foundations or parts of the buildings that still remain in situ, and, secondly, artefacts, including architectural fragments or other types of material culture, that are used to recreate parts of the building that were destroyed and scattered.

5.4.2 Survey Data

Experts also rely on survey data from sites; this includes both archaeological remains and the topography of the site. A differentiation is made between this type of evidence and the actual study of the remains on site because it is used differently in the reconstruction process. Consequently, this section focuses on discussing survey data, including laser scanning data from site.

Although this type of evidence is becoming increasingly important as technologies develop, it was not widely discussed by the experts. As Figure 5.3 shows, only Rawlinson, Wilson, and Saddik mentioned survey data gathered through laser scanning or similar surveying methods as a type of evidence.

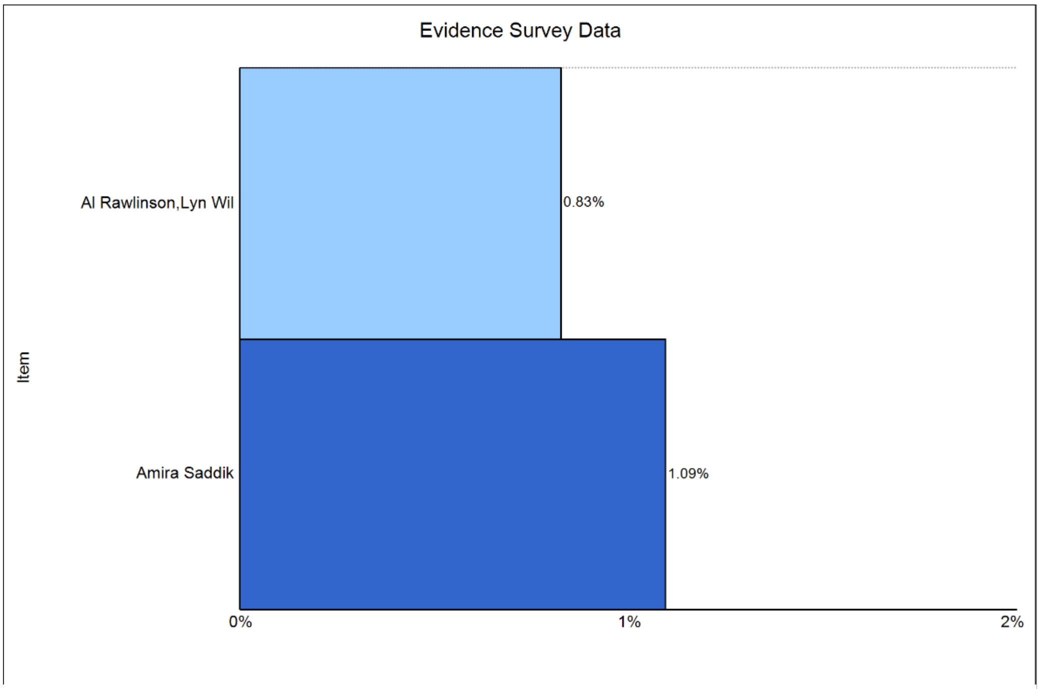


Figure 5.3: Bar chart for percentage coverage of survey data during the expert interviews

For Saddik, in particular, survey data was the first type of data to be collected in the projects she worked on:

> *"The starting point will be through making a survey - they have to be in the field. A very accurate survey is conducted, scanning places, and we took a lot of pictures for everything on site. At the same time, good measures are taken. To rebuild or to reconstruct the first parts of the valley temple is remaining [unrealised] till now." (Amira Saddik)*

Conducting a full survey for the site generates data which is transferred into different media, either drawings, 3D models, or images. This survey data is then used as a base for the reconstruction. Laser scanners and LiDAR scanning are often used, as Rawlinson and Wilson explain:

> *"We used terrestrial laser scanners and airborne LiDAR to generate terrain and ground documentation and models […] heavily relying on terrestrial laser scan data as a basis, […] 3D survey data, […] and terrestrial surveys."* (Al Rawlinson, Lyn Wilson)

Rawlinson and Wilson mentioned the use of laser scan data and 3D survey data several times, and said that they relied heavily on them as a basis for the reconstruction. Laser scan data is not only used in that case for documenting building remains but also for documenting the terrain and ground.

From these quotations it is clear that survey data includes both conventional survey methods, taking two dimensional measurements and images around the site, and using high technology methods in order to generate three dimensional surveys.

5.4.3 Architectural Evidence

Looking at the fragments of a building as architectural evidence involves a different process than simply dealing with them as archaeological remains. Historical buildings often undergo changes through time, so, in many cases, the existing remains do not all belong to the first initial design of the building. In examining architectural evidence, the expert focuses on establishing the original architectural design of the building, and maybe even comparing it with evidence related to similar architecture. This process was mentioned by several of the experts (See Figure 5.4), each offering a different perspective.

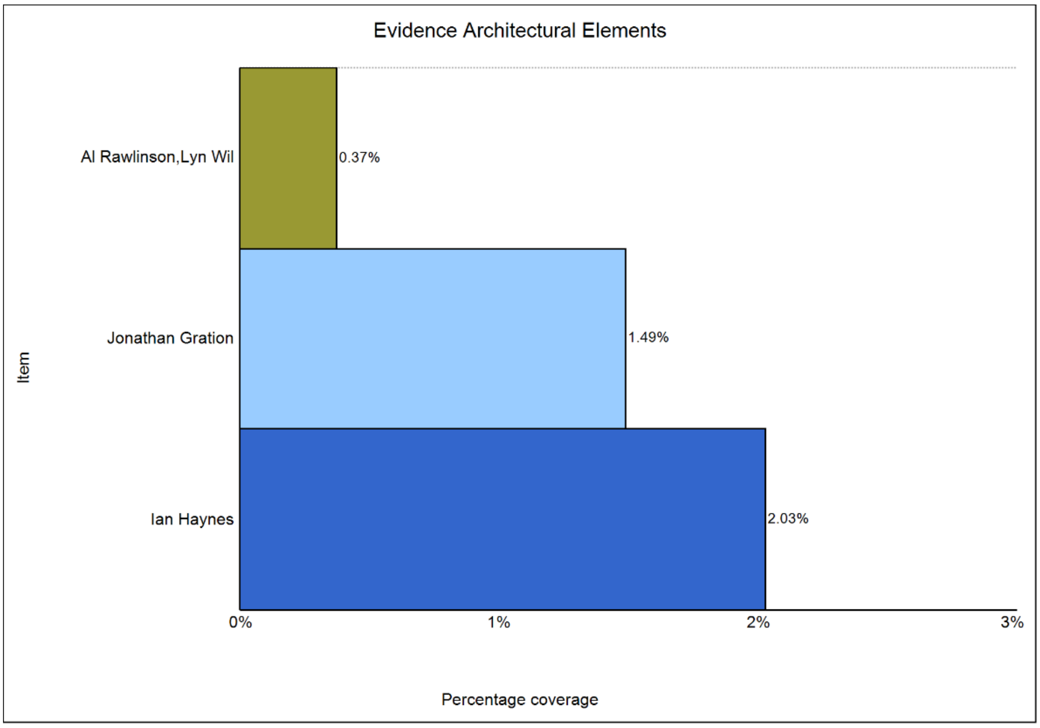


Figure 5.4: Bar chart for percentage coverage of architectural elements during the expert interviews

It requires expert knowledge and previous experience to be able to identify the specific historic period of each part of the building, and Haynes describes the significance of the moment when the original architectural design emerges:

"For me working on the Gandharan site in Pakistan, working on the Latern basilica, there is something quite special about getting this moment in time where the initial architectural conception emerges. There probably was that where those buildings have been successful - they've often survived multiple repairs and patches, and sometimes, changes, and sometimes those changes are superficial, sometimes they're fundamental." (Ian Haynes)

Gration discusses a different type of architectural evidence, namely structural features and his interpretation of them. Even where structural evidence exists, there will be sections that will be incomplete, so some assumptions have to be made through the interpretation process. These are sometimes based on other interpretations, so they become another type of architectural evidence. However other interpretations are not very reliable on their own, so they require further evidence to support them, as Gration explains:

"I don't change the structural features that are present as evidence, you can't move those. You might be able to lower a roof or change the height of it [though] if you see another reconstruction - if you see another interpretation, as long as the evidence is supporting it." (Jonathan Gration)

Rawlinson and Wilson also mention architectural elements in the discussion of the types of evidence they use:

"There were architectural elements which had been found and which had been excavated." (Al Rawlinson, Lyn Wilson)

Haynes focuses on a specific type of architectural evidence: roofing designs and materials. He explains that although few experts pay attention to this type of architectural evidence, it is very important to understand the architectural and structural design of the building and the way surfaces were treated:

"I work a lot on Roman material and roofing tiles; sometimes scholars see it as a part that could be cleared away and not studied although it often could give very important information about everything from roof pitch to the span of the building. But one of the big things is surface treatment. It is one issue to build a convincing space; It is another to actually know how are the walls rendered, and in a number of the projects that I do such as the work I did in Gandara for example." (Ian Haynes)

His comment that knowing the material used in the roof of the remains could give a lot of information related to the span of the building and the roof pitch demonstrates how one piece of architectural evidence unfolds other realities regarding the building. However, this is an indirect and an inconsistent process as a certain conclusion regarding the building can be reached or not depending on the depth of the analysis done, the experts involved, and the level and scope of their experience.

5.4.4 Artefacts In Museum Collections

Artefacts in museum collections may include architectural fragments, as archaeological remains on site, or different types of material culture. Experts often refer to such artefacts during the reconstruction process; however, the process of identifying and consulting them can be difficult as they may be located in different cities or countries. As Figure 5.5 illustrates, artefacts in museum collections were discussed extensively by the experts, who also explained how each type of artefact is used differently in the 3D reconstruction process.

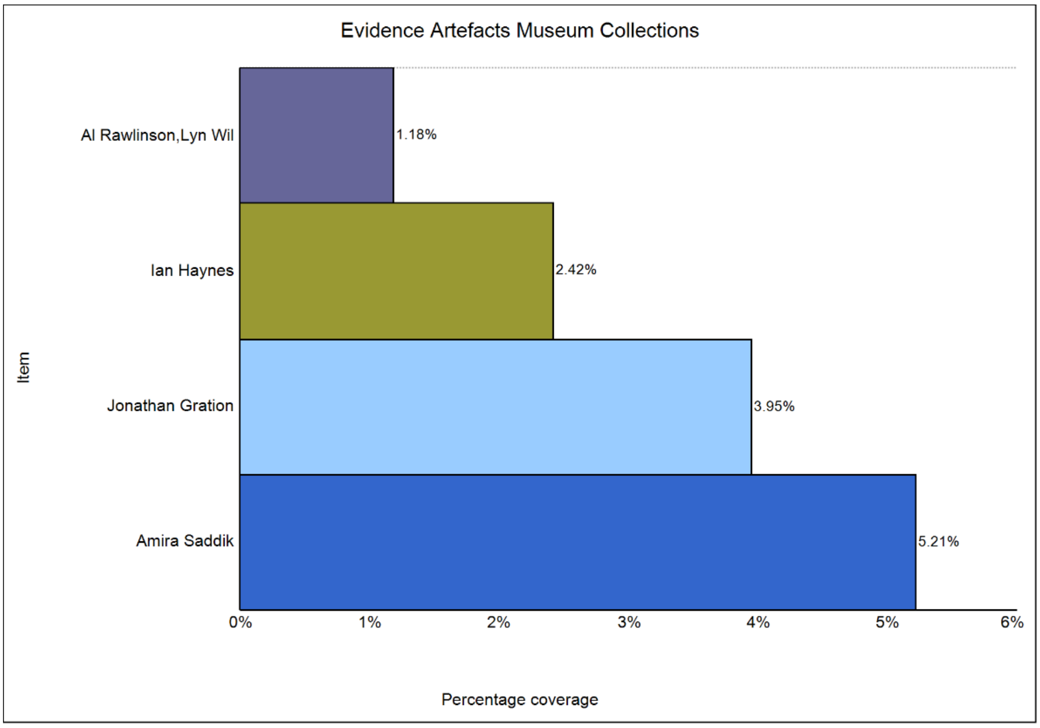


Figure 5.5: Bar chart for percentage coverage of artefacts in museum collections during the expert interviews

Saddik explains that in the reconstruction project that she was working on, they referred to museum collections in the Louvre museum in Paris and the Egyptian Museum in Cairo. Artefacts from these collections were combined with other evidence from site in order to establish a reconstruction. However, some research work also needed to be done in order to determine the exact location of the fragments and artefacts now housed in the museum within the original building:

"For example there was an entrance that included a column, and there was another column that was at the entrance. One of them was at the Egyptian Museum in Cairo. The other one was transferred to the Louvre museum in Paris. We did the research and we brought the whole measurement and all the photos related to both of them. We found that there are two different types of columns - one was at the entrance, the other column was coming from the hypostyle hall. This was a very good discovery because now we had two real measurements coming from the real element (artefacts). […] The reconstruction of the columns is then done and the real measurements are then placed on the real map and the real plan of the valley temple that we generated in the field through drawing the main lines." (Amira Saddik)

Rawlinson and Wilson discussed the importance of using architectural fragments in order to be able to generate a reconstruction. They mention the use of digital technologies in converting artefacts in museum collections into individual 3D models that could either be integrated into larger models or used to build a digital library, depending on the aim of the project:

"We even used the capitals of the columns from the museum collections […] [to create] digitized museum collections […] using structured light scanning and photogrammetry to digitize objects and collection objects and really trying to build up a digitized record." […] This gives you a sense of how this place would have been like, so we definitely feel that artefacts are important." (Al Rawlinson, Lyn Wilson)

Gration also discusses the importance of looking at artefacts as they give a different dimension to the building and its spaces, providing an indication of its function and how the spaces were used. However, he stresses the significance of artefacts that were used inside the spaces, rather than museum collections that consist of architectural fragments, particularly the furniture that was used:

"Absolutely they are very important and also you want to see the connection between something that has been found that is very historical and then what type of space might it come from. I think this is why those items or pieces of furniture that are found in specific rooms in specific villas are important. Then you look at the indicators at the museums giving further information about where each item came from. I think that is very useful to know because it gives you an entirely different dimension as it gives you a chance to see if this was a very rich room or

was it a common space or a sanctuary of some sort, a religious space. The items that you find there really help with the interpretation." (Jonathan Gration)

It is clear again that the evidence found is normally used to learn more about the architectural style and interior design style which is then used to complete any missing evidence.

Haynes also discusses furniture in particular and how it indicates the types of spaces in the buildings and how they were used. One point that he addresses is related to the issue of scale and how those very small structures are then transferred as models into huge scaled virtual buildings.

> *"Yeah, of course, some artefacts are literally micro structures, they are modelled on bigger buildings and that's important [as] some depict buildings that otherwise don't survive; some, such as furniture, you got an example for furniture, they tell us things about the kind of space and how it was used. There are all sorts of examples there. One of the challenges, of course, is then to go beyond that and to consider how artefacts should be placed spatially within any structural reconstruction one does."* (Ian Haynes)

As Haynes suggests, there is a degree of uncertainty in decisions about where to place artefacts within the virtual space. Although there might be evidence that indicates where those artefacts were used within the building, some assumptions still have to be made.

Saddik also highlights the value of using artefacts within virtual archaeological reconstructions, as they provide evidence of both tangible and intangible heritage:

> *"The artefacts is linking the tangible and intangible heritage together. Because here you can know the quality of life and the kind of expertise, and you can know the prosperity even and the economy. This could be known from the kind of materials they use. A lot of information can be found out from the artefacts. Also, when you bring the artefacts in the right place in the reconstruction it brings life, it brings spirit to the building. I have a building here; of course, I know the functionality and, when I see the artefacts, now I get a feeling of the use of the building more. The furniture such as the bed, the chairs etc, for example, adds to the spirit of the space."* (Amira Saddik)

Through investigating and studying artefacts, archaeologists are able to get further information about historic periods, such as the quality of life, the technologies used at the time, and the economy. In addition, as Saddik makes clear, bringing artefacts into the virtual space brings life and spirit into the reconstructed building. This is very important for the public specifically because it gives a better understanding of the function of the building as well as the interior design style.

5.4.5 Visual Evidence

Visual evidence includes photographs of the site, maps, drawings, or any visual material that is related to the site. However, it is one of the types of evidence that does not necessarily exist for all sites, and, therefore, it is not always used in the reconstruction process. As Figure 5.6 illustrates, only four experts mentioned the use of visual evidence in the projects that they worked on, and only Saddik discussed it extensively.

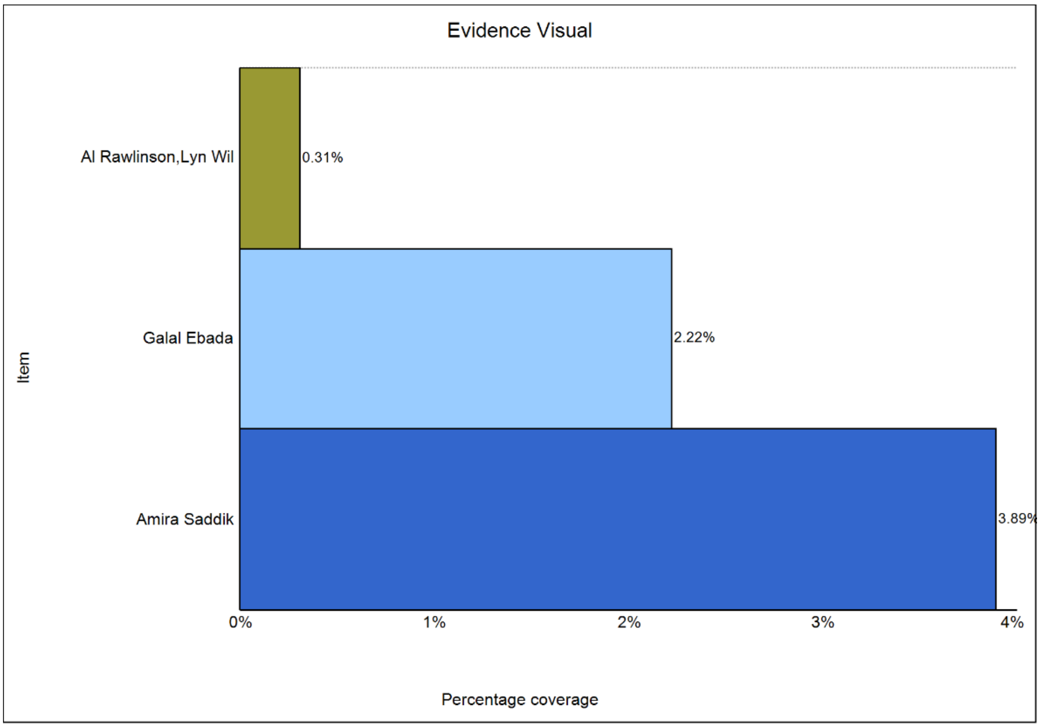


Figure 5.6: Bar chart for percentage coverage of visual evidence on site during the expert interviews

Saddik discusses different types of visual evidence, including photos, either contemporary or historical, maps, architectural plans, and movies and films, and explains how this type of evidence is used to understand the changes that have occurred to the site:

> *"The second type of evidence would be to focus on the different archives related to the site. The archives could be photos coming from contemporary sources, such as photos taken by people working in the excavations in the past 100 years. In the project we were working on, we found photos coming from 70 years ago from the year 1937. They have their own plans, their own photos, and now, when we compare the photos with the real site and the site condition now, it is*

completely different. So we have to see the difference between the site itself 70 years ago and now. Because if we are going to make a reconstruction we have to come back to the latest or the oldest documentation that we have. Photos by archaeologists, maps even photos by the tourists who came since 100 years ago. We even refer to movies and films that were shot in this area." (Amira Saddik)

In some cases, old photos are a good reference for sections of the buildings that have been lost, and they are also useful when the project includes several models of the same building in different historical periods. In that case, the different transformations that the building went through can be presented through virtual modelling based on visual evidence. Saddik also discusses the process of comparing visual evidence with existing evidence in order to be able to reach a consensus.

*"The remains of the foundations that we saw on the field and it was for example covered by a plantation. A number of trees have been coming over the foundation, but we saw that this foundation was very obvious. From a picture that was taken before, around 50 years ago, from Selim Hassan's archive." (*Amira Saddik)

It is clear from the two quotations above that most of the archival visual evidence was collected by previous experts who were doing archaeological excavations in the site. In the case of visual evidence, just as any other type of evidence, it needs to come from reliable sources in order to be valid for use when compared with other existing evidence.

Ebada speaks of working on a project where visual evidence was used in the form of historical maps. Maps are used in certain types of projects where the context is an integral part of understanding the function of the building and its relationship with its surroundings. Maps are a different form of survey data and it might not be as accurate as current survey technologies such as laser scan data but it is still an important reliable resource in the virtual archaeological reconstruction process.

"We are working on a project where the first survey map that shows evidence was in 1955, and it still has some old inscriptions. Through the maps as well you get some discoveries you find information such as the names of different buildings" (Galal Ebada)

Rawlinson and Wilson also referred to the use of visual evidence in their projects; this included "*historical reference images*" , "*previous animations*" and "*drawings... created without laser scan data*". In addition to archival photographs and drawings, they also referred to three dimensional animations. This is a different and somewhat unconventional type of visual evidence; however, due to experts now having the ability to access previous research and previous reconstructions in a three dimensional format and through animations, this is increasingly considered as a relatively valid reference in the reconstruction process.

5.4.6 Textual Evidence

Although textual evidence might not seem, in the first instance, an important type of evidence in a virtual archaeological reconstruction, all the experts mentioned using it in their projects. Although most of them mentioned it relatively briefly (See Figure 5.7), textual evidence is used in many cases, and Saddik discussed the use of such evidence in a detailed way in her projects.

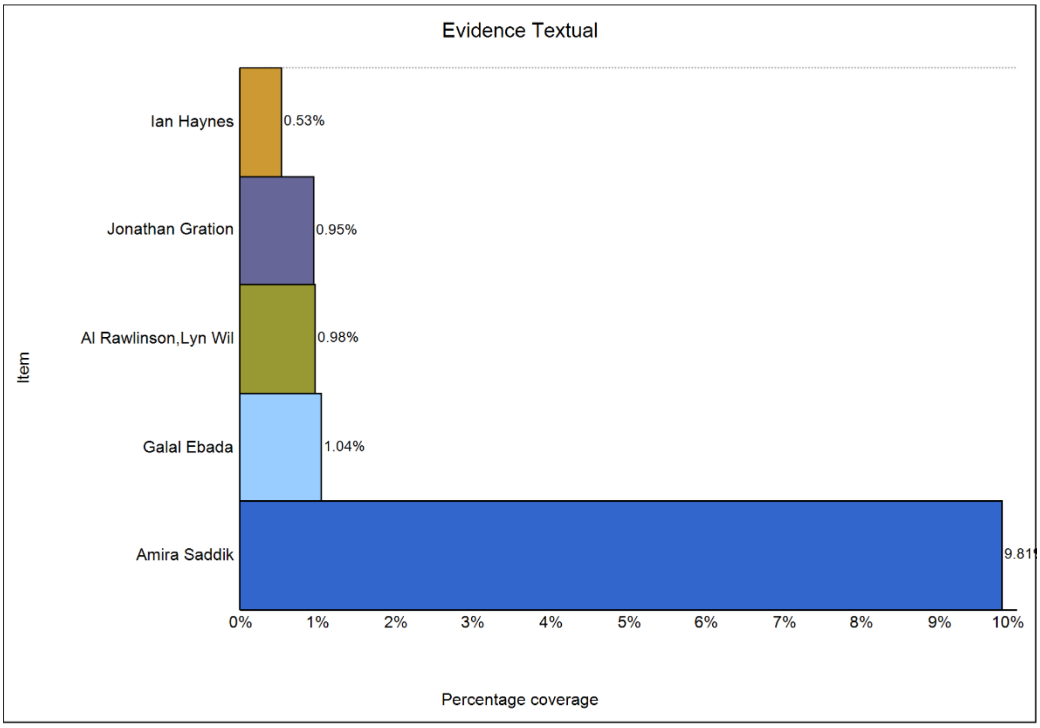


Figure 5.7: Bar chart for percentage coverage of textual evidence on site during the expert interviews

Rawlinson and Wilson twice mentioned that they relied heavily on textual evidence, and it is clear that they take textual evidence into consideration in all their projects, especially when other evidence is in short supply:

> *"We relied heavily on textual evidence and that came to light when we were working with the academic panel to go forward, so, yeah, that was something that was very important; I'd always take that on board. " (*Al Rawlinson, Lyn Wilson)

> "We *didn't have a lot of other evidence we had to heavily rely on written descriptions." (*Al Rawlinson, Lyn Wilson)

The type of textual evidence that they use is written descriptions; however, these require a high degree of interpretation to be able to convert them into a visual 3D reconstruction, which leads to a degree of uncertainty.

Saddik gives more detail about how textual evidence is actually used in projects, explaining how ancient Egyptian text provided data about columns from the temple at Elephantine as an example.. The text not only included information about where the columns came from, but also about the material, the dimensions, and even the shape and prototype of the columns. This kind of information, along with other pieces of evidence, creates a better understanding of the architectural style used and makes it easier to establish a more comprehensive picture of the building:

> *"From the ancient Egyptian text we found, written during the reign of Unas, we found that he is telling us that he brought some columns from the Temple of Elephantine in the south of Egypt. It measured about 15 cubits (ancient Egyptian measuring unit) The Egyptian cubit is about 52 centimetres and, at the same time, the text explains that he made the capital of the column in the palm form. All five columns were in the palm form, and he also explains in the text that he wrote some text on each column related to the measurement of the column and everything. The column in the Egyptian museum, we read the different texts. It was included on the column itself in text, the type of material used, the length and even the shape. This means you have the whole picture."* (Amira Saddik)

> *"The two walls are engraved with the political achievements of the king, the buildings he has constructed, the main projects he has done, the different wars he has fought and his victories, also a documentation for how the economy was like in his reign. If we didn't have the information that these two walls were completely covered with the relief, when I make the reconstruction and I put it for example plain this will be completely out of the function of the causeway. The causeway was like some kind of documentation of the achievements of the king and also it is like a scenario that he has put these achievements. When you look on the North wall you find the topic itself. For example the topic is the different halls that he has done. On the south wall you will find the live scene related to the soldiers in the field while they are making the battle and how there was a victory.*

So to understand the function you have to understand the context and vice versa." (Amira Saddik)

As Saddik explains, the inscriptions not only included evidence about tangible heritage but it also an explanation of intangible heritage. The inscription included narration of the king's political, military and economic achievements throughout his reign, and this kind of data is also beneficial in virtual archaeological reconstructions. This type of evidence may not be directly related to the architectural design of the building, but it is an integral part of the story behind the building.

Saddik further clarifies that although textual evidence is taken into consideration, not all textual evidence should be considered as a reliable resource. The most reliable type would be texts coming from the same era. Other texts could also be taken into consideration, but they have to go through a review process in order to be able to judge the degree of reliability. Textual evidence in that case includes a section covering details about the building in addition to stories and narrations.

"An example for that is related to the causeway of Unas. After Unas has built his causeway, we know that we have the mastaba of the two brothers from the fifth dynasty, and this mastaba was built under the causeway. Unas, when he took a decision that he has to build the causeway here, and he has built the ramp of the causeway on top of these mastabas for example. But we know from the text that Unas has covered some mastabas under his causeway. Even in our reconstruction,s we have reconstructed the causeway with the mastabas underneath, and this was based on evidence not only by Unas himself but based on evidence by other people who came after him. Some evidence even came from the Middle Kingdom - we found some of the blocks of the causeway of Unas that were used in the causeway of El lisht in Hawara." (Amira Saddik)

As Saddik explains in the previous quotation, textual evidence can be very specific, and it can include detailed information about the design, including the various architectural elements, the arrangement of spaces, the materials used, the function of the building etc. All of this data can be used either to model the building through the virtual reconstruction or as an interactive media within the virtual models. Even though the narration and stories might not be beneficial in reconstructing the physical remains, they could be used within virtual modelling in particular as an added fifth dimension within virtual reality experiences.

Ebada discusses a different type of textual evidence, namely archival research and texts. Sometimes, some of the ancient texts about historic buildings are published in digital libraries, but, in other cases experts will have to refer to original resources in archives either in museums or libraries:

> *"Going through archival research is essential because in many cases not all information is published so you have to go to the original resources."* (Galal Ebada)

Those texts are in some cases in different or ancient languages and they might need to be translated. Old books by art historians from different periods are also a resource that experts refer too, but the degree of reliability varies, and this is generally considered as a secondary type of evidence that would need to be compared against actual physical remains.

Haynes mentions that he used textual evidence in one of his projects in the form of Buddhist Sutras. Buddhist Sutras are ancient texts that include teachings of rituals, grammar or any field of knowledge:

> *"I was looking at a Buddhist Sutra for information so those are all different things that one has to look at."* (Ian Haynes)

Sutras are religious and philosophical texts that are not directly linked to architectural design or the use of buildings; however, although they did not describe specific architectural elements, they were beneficial for a better understanding of the philosophy and intangible parts of the archaeological reconstruction.

Gration, by contrast, mentions that he uses textual evidence when there is a clear description of architectural elements, and this in turn informs his modelling of parts of the building.

> *"Yes, I have used textual evidence that, so, if there are references for rooms, if there are openings in the spaces, such as that there was a window, I can show that there was this element." (*Jonathan Gration)

In conclusion, the interviews demonstrate that various types of textual evidence are used by experts, and this largely depends on the historic period as well as the context of the project. The types of textual evidence that were discussed include transcriptions, wall engravings, archives, religious and philosophical texts, narrations and stories, and others. Textual evidence can include explanations of both tangible and intangible heritage that could be used in different ways, either to make decisions concerning physical sections in virtual models or for adding narrations or visual media within the virtual modelling.

5.4.7 Environmental Context, Landscape and Topography

Although environmental context, landscape and topography might not seem an obvious type of evidence for use in virtual archaeological reconstructions, it is an essential part of the reconstruction process according to most of the experts, and it was discussed thoroughly by most participants (See Figure 5.8).

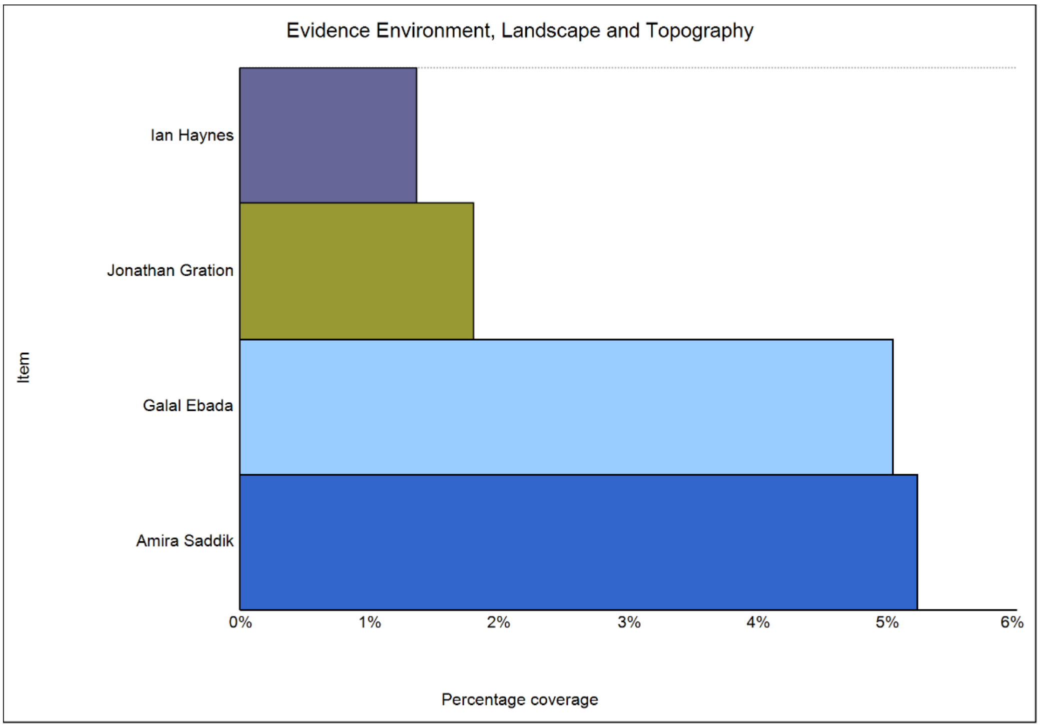


Figure 5.8: Bar chart for percentage coverage of evidence related to environment, landscape and topography during the expert interviews

Saddik in particular refers to a topographical study by an architect in the early 1940s as one of the resources that she used in a recent reconstruction project. This study was important in the reconstruction of the different levels of the building, as the architect focused on generating topographical plans for the different levels.

> *"The valley temple was on the Nile river, the Nile river doesn't reach the area at all. The environment of this area on 2000 years before Christ. We found for example a study that an architect has done before in 1939 – 1942 and he has done very good work related to the topography of the different levels of the platform and how this level of the causeway begins from the zero level to the height of 32 meters. He has done 6 or 7 plans related only to the topography of*

the area and this was very important. This was the first trace that we had the area from the maps and the measurements and we checked it and double checked it from the field." (Amira Saddik)

In some cases, the study of topography is essential when the building itself is constructed on various levels, and Saddik indicates that, for this specific project and case study, it was the most important evidence to begin with:

> *"Like I said before, the topography and understanding the environment are important. For example, the ceiling of the causeway was done with a kind of reconstruction that allows the rain [to drain out]. It was not a very dry area, and, when the rains comes, if the water will be accumulated on the ceiling, it will affect the building. So, the ancient Egyptians did some kind of mitigation through making the ceiling a little bit sloped. The water can then go to the middle of the ceiling through a hole through which the rain comes down into the causeway itself, and then it moves down to the Nile river. Knowing the topography , the environment, and the atmosphere is also a part that you have to put in your mind, and has to be taken into consideration because it has an impact on the reconstruction. For example, in this case, the ceiling can't be straight - it has to be sloped due to environmental influences."* (Amira Saddik)

Saddik also discusses the importance of studying the environmental context. This is important because it gives an indication about the type of materials used, and it also affects the choice of architectural elements, such as roofing, in order to be more suitable for the weather. Understanding the topography, landscape, and the environment are therefore important for some reconstruction projects; it might not be one of the evidence types that has to be looked at in all cases, but it still plays a significant role in enhancing our understanding of the actual physical remains and evidence.

5.4.8 Evidence Function

Understanding the function of the building and the types of spaces that were included within it is also an important type of evidence when taking decisions concerning the reconstruction. In order to make valid assumptions regarding incomplete parts of buildings, it is important to understand the function of the building in order to be able to propose relationships between different spaces, and the spatial dimensions, as well as the details, within spaces, including layout, furniture choices and even finishing materials. As Figure 5.9 illustrates, most of the experts discussed studying the function of the building as part of the reconstruction process.

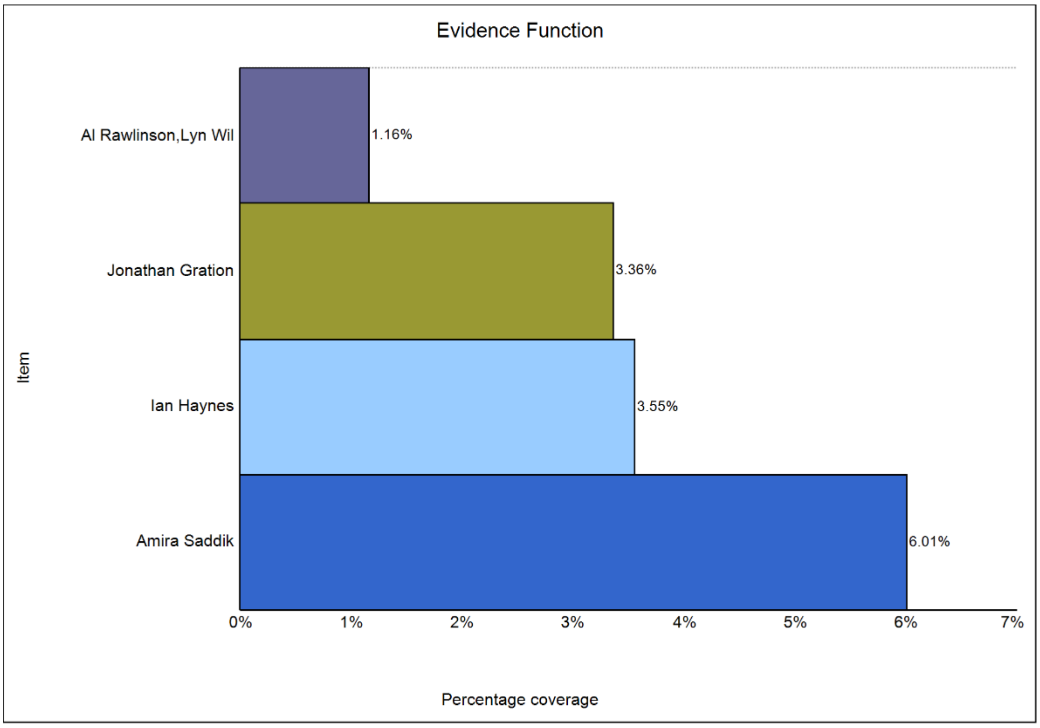


Figure 5.9: Bar chart for percentage coverage of functional evidence during the expert interviews

Al Rawlinson discusses the importance of studying the function of the building in order to understand how the spaces were used, comparing it with existing physical evidence to assist with filling any gaps that might exist within the physical evidence:

> *"If only the foundations remained, then understanding the use and how that building was used by the people is incredibly important. For a reconstruction, we made 3D models, and there were some foundations and foundations of the drainage system that remained on site, so, from those foundations, we were able to then build up some of the areas of the bath house and understanding how the people used that bath house, for example; the process that they would've gone through to clean themselves and to work on that area led to assumptions to how the building was laid out, so, to me, knowing the function is incredibly important."*
> (Al Rawlinson)

Saddik highlights the importance of knowing the function of the building in order to be able to create different scenarios in a virtual reality experience. She explains that it is essential to know the function not only to be able to interpret the data that you have and to create the physical elements of the 3D models but also to generate an interactive model with suitable scenarios that would give the audience further understanding about the building.

"Knowing the function of the building is of major importance to know how you will go through reconstructing the building itself and even to interpret the reconstruction, you have to know the scenario of your interpretation." (Amira Saddik)

"The reconstruction will not be just a reconstruction but anybody [who] sees it will have to know from where to where they are moving, and why I am going through this tour inside the reconstruction- it has to be like a story. I am going here because first I will do that and second, I will do that and third etc. and this is the objective of this building, so we have to know what was the function and the objective of the building." (Amira Saddik)

Haynes also relates the function of the building to understanding how the building and its spaces were used, explaining that this helps in making assumptions regarding missing physical evidence:

"I think one of the points that I want to get at is that the proper understanding of how the space is being used is related to the function, so there is an interplay, isn't there? And, you know, […] I was interested in how, you know, these early Buddhist communities were actually incorporating images and art into the practice of generation. Why did I want to understand how the Constantinian basilica worked? Because I wanted to see how this was going to interact with sound. So, those are all things that need to be considered; so for example, what are the acoustic properties and how this affects the basilica structurally. This is one of the cases where the provocation can help to serve to advance other arguments so it is integral." (Ian Haynes)

Gration, by contrast, focuses more on the influence of scale. He explains that, as the scale of the project is smaller in the case of reconstructing a single building or an interior space, it becomes more important to understand the building function and how the space was used. This is also influenced by the level of detail required in the reconstruction project: as the scale decreases, the level of detail increases, and so it is essential that the function of the building is known:

"Yeah, I guess with urban reconstructions you populate the site with [an] audience to sort of show the built-up area, and you don't have to be concerned with the function of all the buildings. For example, if you have a Roman town and including a Roman temple, those will be the standout buildings; but, whenever I am working on a single building, it is absolutely important to know the functions. Because the

> *same space could be a church or it could be a great hall, and there could be something inside; a kitchen; and that, of course, is very important to know - what are you exactly going to reconstruct."* (Jonathan Gration)

5.4.9 Similar Architecture

Similar architecture from the same period of time, or with the same type of function, or buildings with similar construction methods and architectural elements, or using similar material, are also used as evidence. Most of the experts discussed this (See Figure 5.10), and explained that the type of similarity varies from one project to another, and the way it is used is different depending on the missing information.

Rawlinson discusses the sources of evidence that are used to refer to similar architecture. Most of the sources he mentions are visual evidence, either architectural drawings or photos:

> *"We could use drawings, plans, photographic records from similar architecture to work from and to develop these models of architectural elements as well."* (Al Rawlinson)

Rawlinson also highlights that similar architecture is used as a reference [only] when there is little reference to certain sections of the building:

> *"because there was so little reference for the building, we needed to look at similar structures, similar buildings from that same period to be able to get the architectural details. So, although it is making us do some assumptions, it is still making assumptions based on evidence, so it is looking at similar time periods, similar cultures, and then applying them to the reconstruction that we would be producing".* (Al Rawlinson)

It is clear that Rawlinson uses these resources strictly for generating architectural elements. This indicates that normally, when there is reference to similar architecture, the focus would be on completing missing sections of the building rather than changing the layout. Therefore, it is not a first priority evidence type when generating a reconstruction project, but it is used when other evidence strictly related to the building itself does not exist.

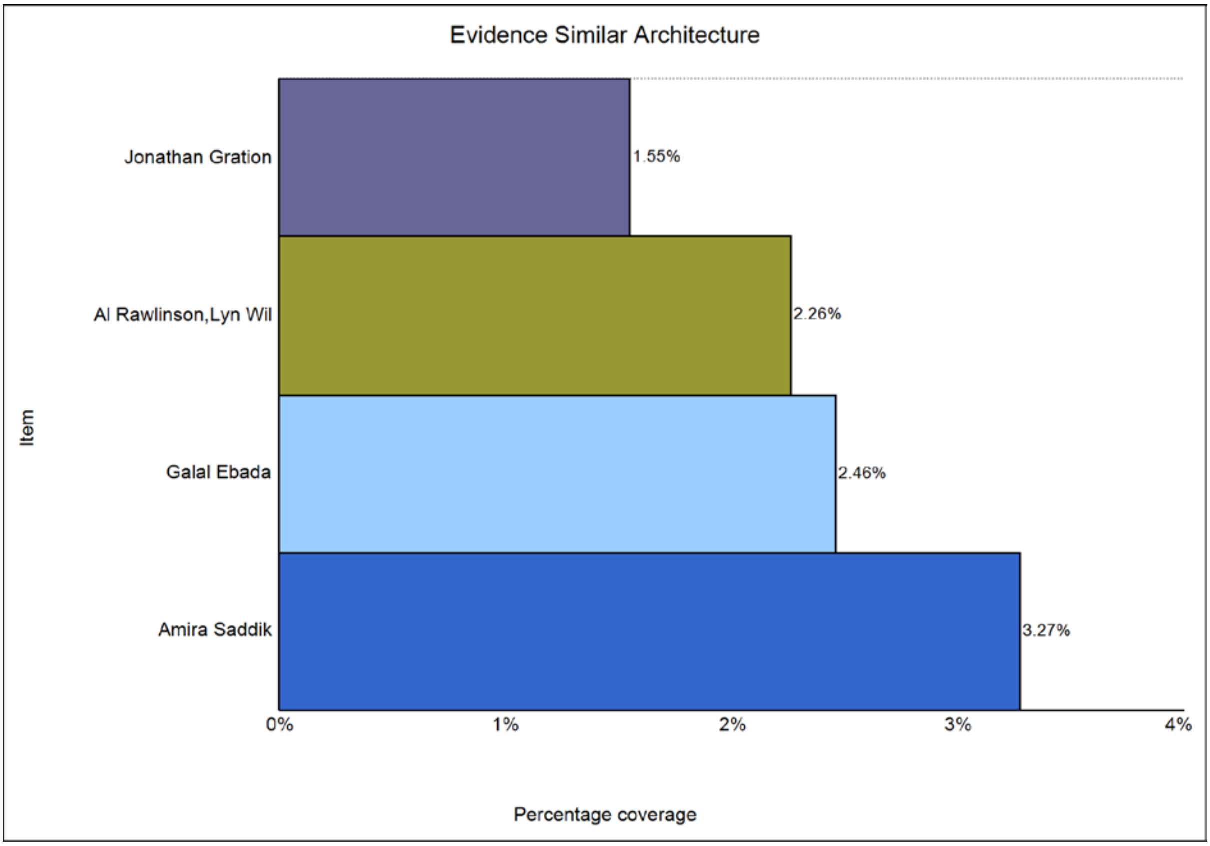


Figure 5.10: Bar chart for percentage coverage of similar architectural evidence during the expert interviews

Ebada, having an architectural background, mentions the importance of studying architectural styles and taking them into account while creating a digital reconstruction:

> *"Sometimes we rely yes on previous knowledge of architectural styles." (Galal Ebada)*

Here there is a differentiation between the idea of studying an architectural style, which would be an approach used by architects in reconstructions, and archaeologists and art historians who rely more heavily on physical evidence.

He goes on to give an example from previous research work that he conducted himself. The project included the reconstruction of a minaret that was lost, and the research team had to go study the architectural style of the period, as well as of the region, in order to generate a replica of the lost minaret from a mosque which was similar, both in terms of the period as well as the region:

> *"Minarets in Andalus and minarets in north Africa are different than minarets in Damascus; both are classified under the silos type of 'minarets', but the top part is different in each of them, the treatment of the openings is different, this is why we had to choose only one."* (Galal Ebada)

Gration, meanwhile, discusses the difference between referring to similar physical architecture versus other digital reconstructions. He indicates that he prefers to refer to similar buildings that still exist rather than historic or modern interpretations. He explains that this is because using an interpretation as a reference contributes significantly to the subjectivity of the final 3D reconstruction:

> *"If I am reconstructing a medieval abbey, I don't necessarily use other archaeological interpretations of a medieval abbey I prefer to try and find a still standing abbey first. Otherwise you are extrapolating from an extrapolation, so I'd rather try to find a built version."* (Jonathan Gration)

This then positions similar architecture as a more reliable reference when compared with previous reconstructions.

5.4.10 Contextual Comparisons

Contextual comparisons resemble studying similar architecture in the sense that they both involve studying something that is not directly related to site but which can give important information that generates a better understanding of the architectural design. Comparing the site to others from the same period is one of the approaches that is used to make assumptions when parts of the building are lost, and contextual comparisons can also include study of the historical period as a whole to reach conclusions related to the architectural style at the time. Again, most of the experts discussed this in detail (See Figure 5.11), explaining the different approaches to using contextual comparisons in the reconstruction process.

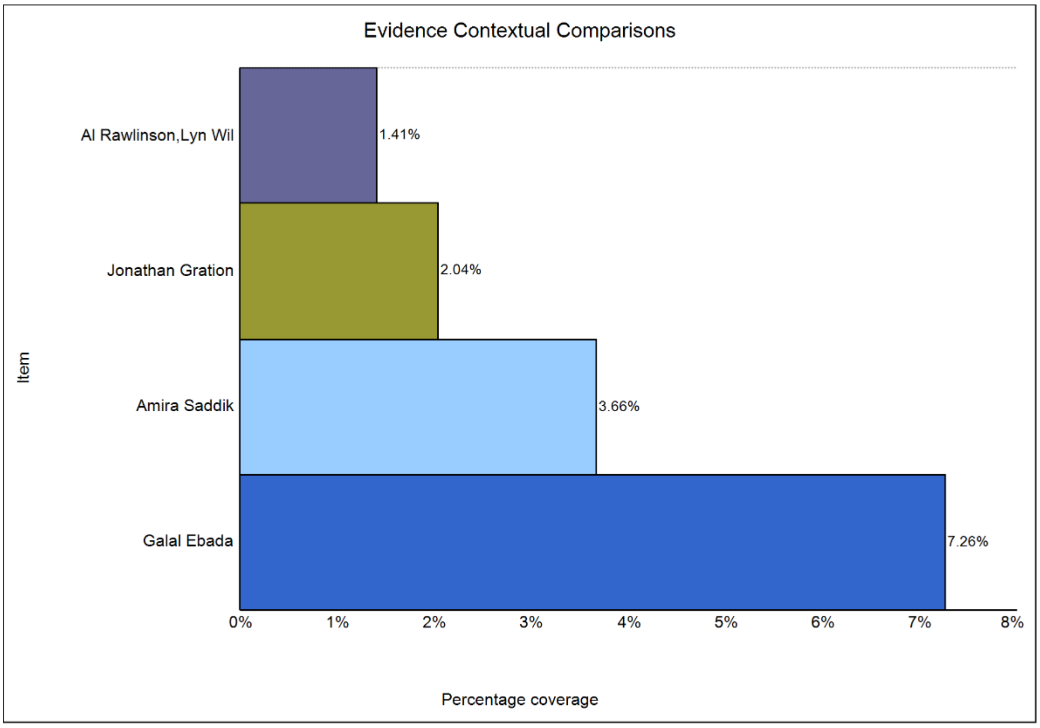


Figure 5.11: Bar chart for percentage coverage of contextual comparisons during the expert interviews

Saddik refers to studying the history of the fifth dynasty and the architecture of this era in the process of reconstructing a building that was built at the same time.:

> *"When we are generating an interpretation for the fifth dynasty, I have then to go through the whole kingdom, and study all the kings of this dynasty. How they built, what is the materials they used, even, for example, I referred in my work to a causeway done in the reign of Sahura which is one of the previous kings before Unas but related to the same dynasty. We studied the causeway of Sahura through photographs as a reference."* (Amira Saddik)

She also indicates that further historic study was conducted to understand the previous time periods, especially the fourth dynasty, as it had a direct influence on the architecture of the fifth dynasty:

> *"We then compared this information with other types of evidence because, of course, it will influence the interpretation of the 5th dynasty. Unas was living at the same time and he has to be influenced by the architecture of the 4th dynasty, and the previous kings, and even by people who have built around him - that is why we have to look at that as well."* (Amira Saddik)

Ebada, on the other hand, focuses more on contextual comparisons related to geographical locations, drawing on the architectural differences between minarets in Damascus, Syria, and those in other locations to demonstrate the importance of both historical and geographical contexts when faced with contradictory evidence:

> *"Both [minarets in Andalus and north Africa and those in Damascus] are classified under the silos type of minarets, but the top part is different in each of them, the treatment of the openings is different - this is why we had to choose only one. After we made an initial choice of using the type in Damascus, we thought that they must have hired workers and builders from Al Sham [Syria] not to build like the one in Andalus, so that was our choice based on likelihood, but it might be seen as a weak evidence or that it is biased in a way."* (Galal Ebada)

Gration also discusses the use of contextual comparisons where other evidence is unavailable; however, he warns that they may not be helpful if they depend too heavily on other countries and contexts:

> *"I haven't had the luxury of working in a location where there was a lot of contradictory evidence. You'll notice that a lot of the archaeological interpretations in England tend to rely heavily on what happens in Rome, which is very unlikely to be correct in relation to what was happening here. So we have to use that up to the point that you have actual evidence."* (Jonathan Gration)

5.4.11 Previous Reconstructions

Opinion is divided about whether a previous reconstruction of a site can be used as a valid reference because it is based on a previous interpretation. However, it is clear that some of the experts consider it as a valuable resource if the reconstruction is created via an acceptable academic approach and has gone through a proper review process. This topic was discussed by most of the participants, notably Saddick and Gration (See Figure 5.12).

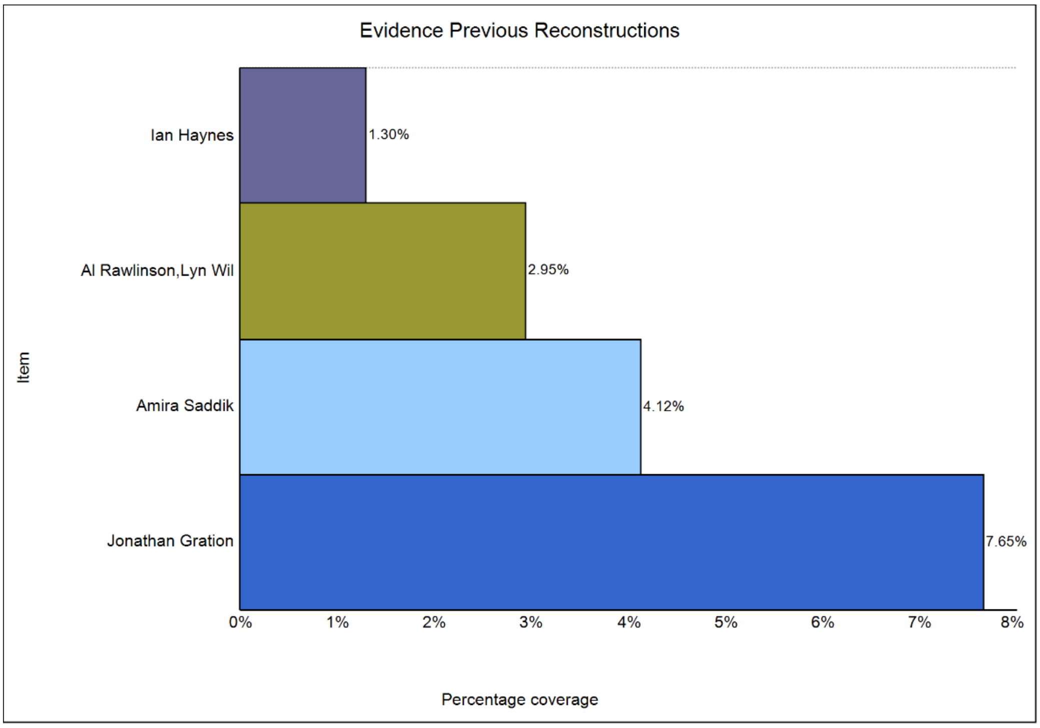


Figure 5.12: Bar chart for percentage coverage of previous reconstructions during the expert interviews

Rawlinson states that he thinks previous reconstructions could be used as a valid resource if they go through a rigorous enough academic review process. He speaks of a specific case where he and his colleagues used a previous reconstruction as a basis for their reconstruction:

> *"We have used previous reconstructions in the past, again if the previous reconstruction we are using has gone through the same rigor and process and has been reviewed. We can use it, we have done that with a previous project where we have used work that other artists have created as a basis, because that whole process of reconstruction has already happened in that project and we were then able to use that."* (Al Rawlinson)

The reason for taking the previous model as a reference was to avoid duplicating work that someone else has already done. However this is a debatable point because this means we are building an assumption on a previous assumption. Rawlinson goes on to explain that part of being sure that the model is rigorous enough is to investigate how it was created, treating 3D evidence in exactly the same way as 2D evidence in terms of assessing its validity and reliability:

> *"We need to understand how it was generated and why certain things are there, and we need to have confidence how this model was created. It is the same as 2D sources – we have to investigate the source, we need to understand how that has been generated and the evidence behind it as well. So, in that context I really don't see the difference between a 3D model and a drawing, but we have to be sure and confident that it has been created based on evidence, so everything comes back to evidence*." (Al Rawlinson)

Saddik goes beyond considering previous reconstructions as secondary evidence, describing it as an important type of evidence that has to be included in the process. She mentions that this is especially the case when the reconstructions were done by specialists who visited the site in a previous period, as their reconstructions or drawings of the site could be considered as a visualization of the state of the site at the time:

> *"We have to refer to previous reconstructions, this is a very important resource. Because sometimes the reconstructions that have been done before are done by previous specialists in the field and in ancient Egyptian civilization. (Mariette, Naville) Those experts have seen the real sites 60 or 70 years ago with different features that we can see today. A lot of things have been removed from the site today. A lot of the evidence has been presented through their work and their reconstruction, so their reconstructions are very valuable."* (Amira Saddik)

For Saddik, close examination of previous reconstruction and the notes made by their creators provide insights which can lead to new discoveries and different types of evidence:

> *Sometimes it can bring keys for a new discovery. For example, the reconstruction of the temple of el deir el bahary - there have been two previous reconstructions, one was done by Naville and another was done by Mariette. From both of them and from reading carefully all their notes, we can discover new things. We discovered another part of the temple which is not at the same place now as it was transported to the third level of the temple, but in the original building it was part of the second step. This is why we have to search for the previous reconstructions and study them carefully."* (Amira Saddik)

Gration, on the other hand, mentions that he uses previous reconstructions in some cases, including his own, but these are not considered as essential evidence. Like Saddik, he has used previous reconstructions in the form of drawings rather than the 3D models which Rawlinson describes:

"I do sometimes refer to some of my previous reconstructions. I use it to check the change in my skill level, but I also relied on or used [previous reconstructions in] projects where there were reconstructions in the format of drawings, so not digital or 3D files. In a reconstruction I did for a castle, the University of Leicester had some drawings, but it was more plans and sections but not really a 3D model, so I never had any 3D data to use to start building the reconstruction. I do the interpretations on my own but I never used previous digital data." (Jonathan Gration)

Gration also criticizes the misuse of previous reconstructions to inform the reconstruction of other similar buildings without sufficient evidence to support this. He also raises the issue of making assumptions based on previous assumptions which weakens the credibility of the final model:

"I have seen projects, such as a chapel I remember seeing, where they were clearly inspired by another digital reconstruction of another chapel in another part of the UK in the same period, although this chapel had a much richer interior, and there was not enough study, and without actually questioning if this type of stained glass, murals or even this type of vaulted ceiling would've been available for the other reconstruction as only the foundation survived. They just extrapolated these elements onto the digital model. In a way it is fine because it is also a 14th century chapel with the same aisles, more or less, but then, once you start talking to historians, they would say that this one would've been a lot richer, and once you start looking at churches in the area, there weren't any with vaulted ceilings." (Jonathan Gration)

Haynes also cautions against the use of previous reconstructions or visualizations due to their greater impact on the researcher because visual media always has a stronger influence than text. This is why he stresses the need to be very cautious while using them as a reference:

"I think the problem with those is that previous visualizations have a power more than the text. This is a real problem; yes, we probably do use them, but sometimes I think they use us too. That's why I think you've always got to see this, as I say, as a provocation." (Ian Haynes)

It is clear that the type of available evidence changes from one project to another, and not all case studies will have previous three dimensional or even two dimensional reconstructions. However, while previous reconstructions have the potential to offer valuable insights, care must be taken to establish their validity and ensure that their visual impact does not lead to inappropriate assumptions being made.

5.5 Representing the Subjectivity Of Digital Archaeological Reconstructions

As discussed in the previous chapter, it is clear that the subjectivity of digital archaeological reconstruction comes from two main factors: the evidence and the expert. In light of the analysis of the experts' opinions on the types of evidence used and their reliability set out above, it is possible to develop a hierarchy of evidence, from the least subjective to the most subjective see Figure (5.13). In addition, analysis of the terms used by the experts to signify the subjectivity within the reconstruction process enables a linguistic hierarchy to be developed.

5.5.1 Creating a Hierarchy of Subjectivity in the Evidence Types

Physical evidence from the site itself is considered to be the most reliable type of evidence with the least degree of subjectivity. Survey data collected from the site by the project teams is considered to be the most accurate, due to the use of high end technologies that provide a very accurate transfer of evidence from the site to the experts. Archaeological remains on site are also considered a very reliable source; however, they follow survey data as they may be subject to a degree of error due to the involvement of experts in the interpretation of the evidence from the site. Artefacts in museum collections are also seen as a highly reliable resource, but they undergo an interpretation process as well as a transfer from the site, and these mean they can be more subjective than evidence on site. Both textual and visual evidence are widely used in reconstruction projects, and, if they undergo proper scientific rigour and are found through reliable archives, are considered as strong pieces of evidence within the reconstruction process. Both are direct types of evidence that describe the site specifically, either through text or visuals; this is the reason why they are placed after existing remains as moderately reliable evidence. Although previous reconstructions are influenced by the personal interpretations of the experts who created them, they are still a valid reference, as they relate directly to the site, but they hold a degree of assumption and imagination, which must be recognised. Experts also rely on evidence not directly linked to the archaeological site, such as contextual comparisons and similar architecture; however, these types of evidence are less reliable as they are typically used for creating missing parts of the buildings that lack alternative forms of evidence, so they carry a high degree of subjectivity. There are also intangible types of evidence, such as information regarding the function and use of the building and its spaces and the environmental context; however, these are considered the most subjective as they are not based on tangible physical evidence.

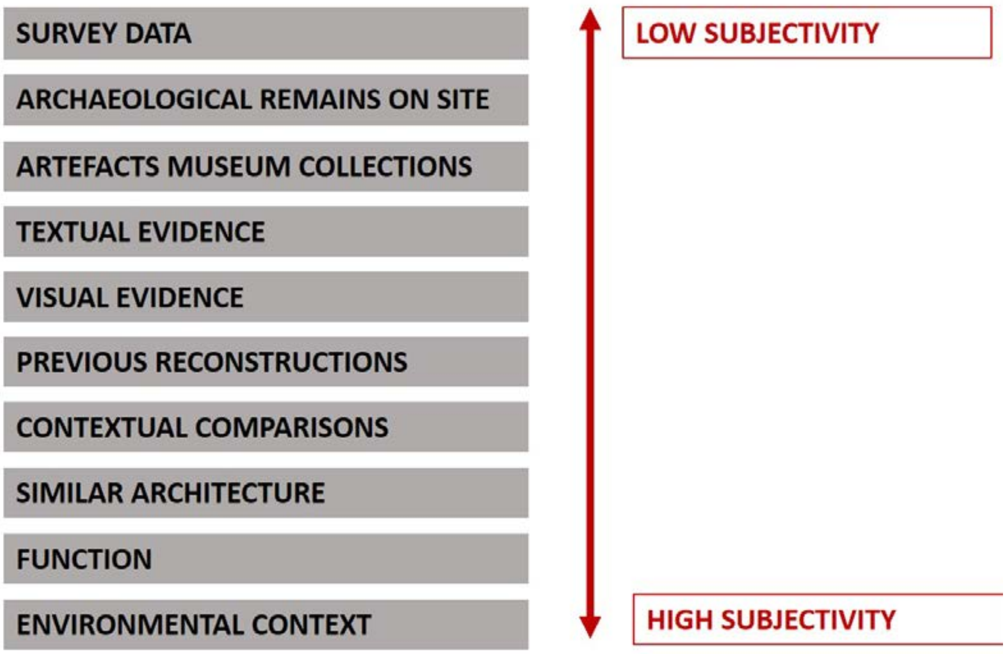


Figure 5.13: Hierarchy of evidence from least subjective to most subjective based on the experts' interviews

This classification is itself quite subjective as it has been reached through analysis of the experts' opinions. However, in each case, even evidence that is thought to be more reliable should undergo rigorous study, considering the source and how strong the evidence is. This involves a lot of investigation, and it is quite difficult to identify it as a systematic procedure. It is, however, a process that goes back and forth through an interrelation of evidence until the experts reach a conclusion and make a decision regarding the reconstruction. However, it is clear that there is seldom sufficient evidence that would make experts completely certain of how the building actually looked.

5.5.2 Ranking the Words Which Reflect Subjectivity

In addition, an analysis of the subjectivity of digital archaeological reconstructions was conducted. This included a word frequency study for terms used by the expert interviewees to indicate the existence of subjectivity in the digital reconstructions of archaeological sites. The terms that were included are not all directly related to subjectivity; however, they reflect the fact that there is an element of subjectivity within the process for numerous reasons. Figure 5.14 provides a word cloud for the terms that were found to reflect subjectivity.

Figure 5.14: Word Frequency Study

It is clear that “interpretation” and “interpretations” are dominant within the word cloud, and both archaeology, as a science, and also archaeological reconstruction, whether digital or non-digital, are based on interpretations. The process of interpretation involves making choices between several alternatives, and terms that the experts used that indicate this include *“Alternatives”*, *“Versions”* , *“Variables”* , *“Choice”* , *“Options”* , *“Suggestions”* , *and “Several”.*

Peer review and discussions are key elements of the digital reconstruction of archaeological sites, and the review process in itself indicates the subjective nature of the reconstruction process. During the interviews, several terms were mentioned which indicate that debate and discussion is involved in order to reach a consensus between several experts. Examples of terms that were used in this context are *“Consensus”* , *“Debate”* , *“Disagreeing”* , and *“Consultation”* .

The process of expert interpretation involves a high degree of subjectivity that arises from personal judgment. This judgment is certainly based on knowledge, but it also relies on personal guesses, imagination, innovation and creativity. This was clear through the discussion with the experts around decision-making through the reconstruction process, and it starts with taking the different types of evidence and extrapolating certain information from them. Extrapolation, in this sense, is a form of creativity. Extrapolation is followed by making assumptions and by imagining certain incomplete parts from the evidence. Terms such as *“Extrapolation”*, *“Extrapolating”*, *“Analogy”*, *“Assumptions”*, *“Imagine”*, *“Imagination”*, *“Innovation”*, *”Open mind”*, *and “Guess”* were all used by experts and indicate the extent of the subjectivity, that even reaches the degree of imagination or innovation in some cases.

The experts also discussed their decision making regarding the evidence and the final consensus they reach. Several of the terms that were used show that there is normally a degree of confusion, doubt, and hesitation in the reconstruction process, as experts may be certain or uncertain about specific evidence as well as their own interpretations. So, the evidence as well as their own interpretation varies in the degree of reliability, and this affects the degree of confidence they have. Terms that were mentioned during the interviews that indicate this aspect include *"Hesitation"*, *"Confusion"*, *"Doubt"*, *"Uncertainty"*, *"Certain"*, *"Confident"*, *"Reliable"*, *"Confusing"*, *and "Changing" .*

As for the evidence itself and its reliability, there is a degree of subjectivity within that as well. The subjectivity arises from the information and sources themselves, and there was a clear association with that through the interviews. Experts described sources and information in some cases as including errors, vagueness, and even fraud. The following terms were therefore considered to contribute to the subjectivity: *"Fraud"*, *"Error"* , *"Vague"* , *"Information"* , *and "Sources"* .

It is clear that subjectivity exists in each phase of the reconstruction process, in the evidence itself, in individual mental processes, in the peer review and discussion between different experts, and in the decision-making process. In the end, a final judgment has to be made, and this often requires compromise between experts, unless one evidence type is judged to outweigh others or one opinion carries more weight. After the debate and the uncertainty comes the decision, which is also, in a sense, subjective. The terms that indicate this phase of the digital reconstruction were identified as follows: *"Compromise"*, *"Outweighs"* , *"Biased"* , *"Judgment"* , *and "Judge".*

Figure 5.15 shows all the terms mentioned during the interviews that are linked directly or indirectly to subjectivity. These are presented in a hierarchy from least to most mentioned; the diagram also shows the length of time each term was discussed and the weighted percentage (based on the word count of each term and length of time it was discussed). As the hierarchy shows, the experts mentioned "different interpretations" numerous times during the discussions. This is one of the key defining factors for the subjectivity of digital archaeological reconstructions, as the process of interpretation is always different and always subjective. Many terms were mentioned only once; however, these were typically synonyms for more widely-used terms where there was a pattern for understanding the different forms of subjectivity that arise during the digital reconstruction process.

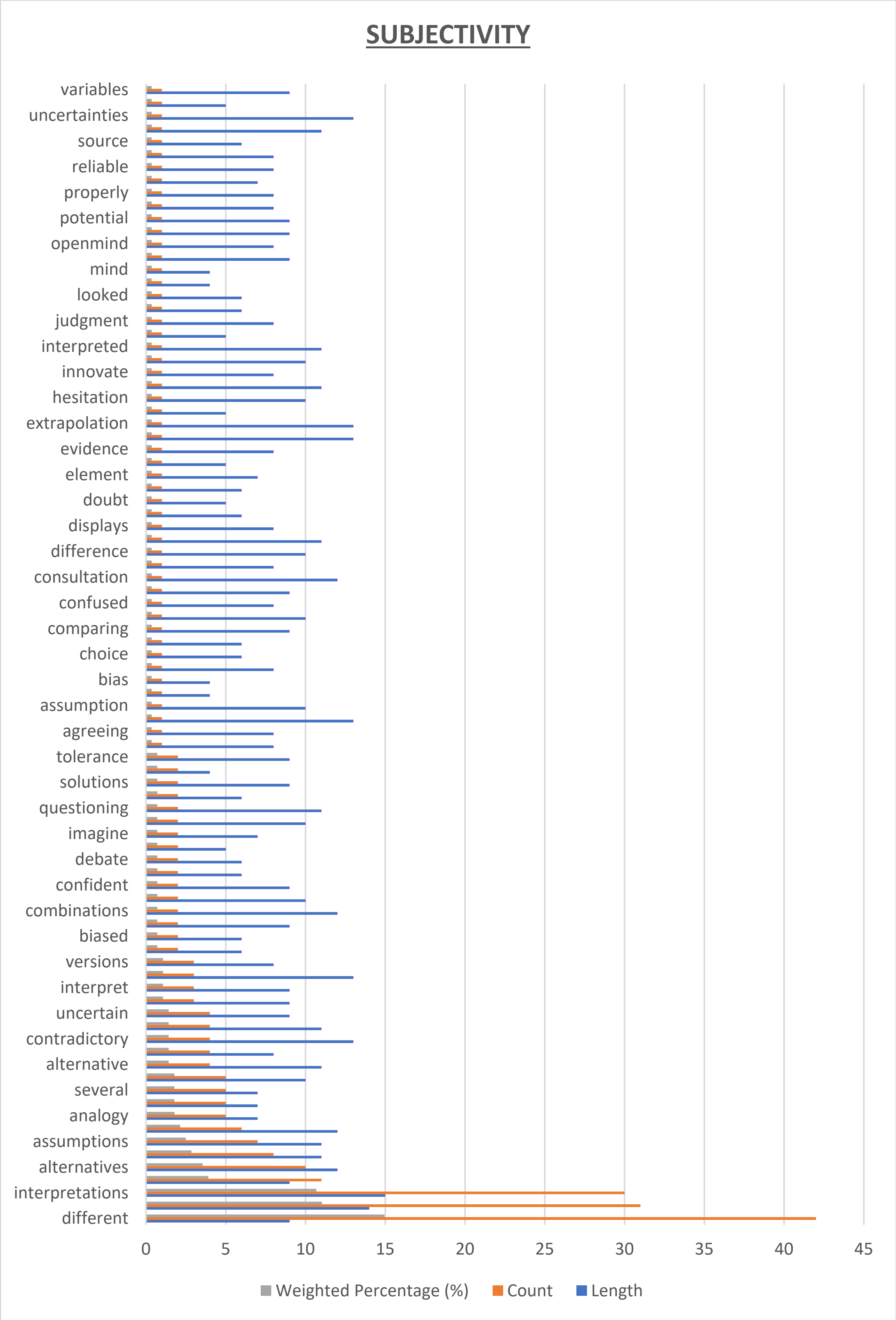


Figure 5.15: Word count reflecting subjectivity

5.6 Virtualizing the Subjectivity of Digital Archaeological Reconstructions

The final section of the interviews focused on taking the experts' opinions on using virtual reality as a technology to represent the subjectivity of digital archaeological reconstructions. No clear consensus on this topic was found among the experts, possibly due to the fact that this is a relatively new field of research; however, the discussion led to a number of recommendations that could be used as a guide for using virtual reality in this context. In the following sections, a number of approaches for using virtual reality mentioned by the experts are presented, and these will be used as a guide for the case study application in chapters 6 and 7.

As Gration explains, a key issue in relation to the use of virtual reality to represent subjectivity is the lack of clear guidance within the field about how it should be used in practice:

> *"I think there are huge opportunities for virtual reality to be able to integrate those different degrees of uncertainty within the model. The problem at the moment is that there is no clear consensus in what this uncertainty is and how you represent it. So if you are using a heat map, then you might say red is certain and blue is not certain, and somebody else might do it the other way around, so there is no consensus about how you do that and how does that help. And then, even if you have consensus among your peers on how that might be, the public don't necessarily know that blue is certain and red is uncertain. It has the potential, but it has to be linked to some kind of agreement in the field. Otherwise every single reconstruction will have to be explained and contextualized first before using it for public engagement - not that that's bad, but it just adds another barrier. " (Jonathan Gration)*

Gration's comments about the difficulties of representing subjectivity to non-experts were echoed by other participants, who mentioned that it would be challenging to present multiple interpretations or uncertainty in parts of the models to non-expert audiences. There was a general concern that, despite virtual reality's capacity to engage audiences, this might be confusing and might mislead them. Haynes, for example, said:

> *"I think you know one of the reasons I think it is important is that it adds value to people thinking through the process, it maximizes public engagement but it still comes back to the same points that we discussed earlier with regards to the London Charter you know you can mislead people as well as help people, I think when one uses something like that it becomes very, very important to incorporate*

into it the capacity to be informed about this. So you know I think with many of these there is every ever reason to believe that you can incorporate another tier that can be switched on and off that gives the reasons why something is visualized the way it is." (Ian Haynes)

For Haynes, it is important that it should be used with a very clear focus on the audience and to make sure that they are properly informed and that the visualization techniques used are suitable. With this in mind, the following section explores the different approaches for representing the subjectivity and uncertainty of digital archaeological reconstructions discussed by the experts.

5.6.1 Integrating Multimedia

One of the approaches that the experts mentioned is integrating multimedia into the reconstructed models using virtual reality. This has endless applications, and the media that could be integrated includes visuals, sounds, and even three dimensional models. This approach could be used to integrate data about the models, including the evidence used to generate them, or even how the models were created and the methodologies used. The following quotes by Ebada and Rawlinson and Wilson provide examples of how this could be used in applications:

"There is a difference between representing different alternatives and the need to add further data for clarification in the form of multimedia, such as adding text. " (Galal Ebada)

"What we can do is present physical evidence in terms of the 3D data - we can visualize that in terms of the 3D reconstruction, and they can actually bring it then to life by understanding how it was used. [It's] not just about creating four walls - it is then about how those spaces were furnished, what people would've done with them, how the spaces would've looked, how people would've interacted with them, and all of these things build a much richer picture of how this place would've looked." (Al Rawlinson, Lyn Wilson)

5.6.2 Presenting Several Interpretations

Another approach would be to actually combine several interpretations of the site into the same virtual reality experience. This could be achieved by alternating between the different models or even by having several models within the same environment. However, Ebada thinks that the presentation of several interpretations should only be used with experts rather than with the public as it could create confusion.

"I think representing different interpretations and subjectivity is not addressed to the public, the models that are used for the public are only one type, they are normally used in museums, they just see the models in the museum and that's all - they don't question if there are other alternatives or if there is scenario B or Scenario A. It is not that flexible with the public to get them into a dilemma; on the contrary, this generates a high confusion to the message you want to give and to the user experience in the museum or in the media you are using for display. […] You must avoid this, you take the responsibility of one single scenario, but the idea to represent different scenarios to the public within a certain itinerary in a museum this will confuse the public, unless it is quite essential to represent two alternatives - but that would be in very exceptional cases." (Galal Ebada)

This is a debatable point as it would also depend on how the models were presented to the public; this may also change depending on the aim of the project, as discussed in the literature review. Haynes, by contrast, explains that the several interpretations could be presented to different audience using different levels of explanations; for him, it is a matter of the user interface and how it should be designed to suit the general public. He also explains that the type of information and explanation integrated into the model should be well adjusted to suit the target users:

"At a certain point in every given model there will be those buttons which tell people 'Right, at this stage we are going to walk you through the different interpretations', and I think that balances the facts. I think there are different aspects there; I mean, exploring Hadrian's wall is one of the examples where we investigated doing different interpretations and each [was] accompanied importantly by three tiers of explanation. So a basic explanation that is available to anybody, sort of the simple label "what kind of building is this", the second one which elaborates, and a third one which includes the bibliography for that particular site." (Ian Haynes)

Saddik also discusses using different types of models and explanations for different types of audience. She explains that it is possible to present several interpretations to public users on the condition that the model is developed in a way that suits the type of user. According to Saddik, using virtual reality opens up space for creativity and for developing a deeper understanding of the site.

> *"I have a chance to interpret it and present it to people coming from primary schools and secondary schools and even architects who are coming from the Faculty of Engineering, and each one of them has a different scope when using virtual reality, and there is a whole imagination field in using virtual reality and it opens a field of innovation and even a field to create and that it comes with an added value. So, the different interpretations of the same site using virtual reality - I think this is a very good media if this is represented in the right way and to put explanations, because you have to be very careful with this. It will be a very positive way to open minds and create, innovate, and even to add more value to the same site. Presenting different scopes to the audience." (Amira Saddik)*

Gration gives an opinion that presenting several alternatives could be best used when developing a reconstruction for the same building through different historic periods:

> *"When it comes to a conservation project, especially when there are multiple options or uncertainties in the construction, then the reconstruction comes into a digital reconstruction. It is used to offer different alternatives to visualize how it used to look back in 1720, rather than 1750 - what that space would look like then. You can really use the digital reconstruction to help make that decision and help show evidence for all those different options as well as help in the fundraising to be able to conduct the actual conservation of the project. It is a plus before even doing the intervention. The last type of project I mentioned is audience engagement; that really depends on what's going on - is it the exhibition, is it the museum? Does it have to be on site or off site? The parameters are very different." (Jonathan Gration)*

This comment by Gration gives a different dimension, indicating that presenting different alternatives will depend on the type of project and aim and should not be followed in all cases but only when there is a specific aim to achieve.

5.6.3 Interactive Environments

Interactive environments have numerous applications that could be used to enhance virtual environments. Interactivity adds so many possibilities that help the users to integrate with the models. Rawlinson and Wilson discuss using interactivity within virtual reconstructions and how it aids in engaging with the spaces and having more immersive experiences that will enhance the users understanding of the history of the site:

"If you can see tangible objects, and you can imagine taking things up, and you can imagine interacting with them, and, for virtual reconstructions and especially within virtual reality, having things that tie you to a space and let you engage with a space, makes it a much more immersive experience - so it is really important." (Al Rawlinson, Lyn Wilson)

"Rather than just having a pre-rendered fly-through animation, we want sites that are explorable and people can then go and interrogate – so, for us, that has been a big change in the last, maybe, five years, where our resolution for the 3D data that we capture on sites can be presented in this way then also we can then expand on that with the 3D reconstructions. Virtual reality allows us then to present that in a much more immersive way, so we get a greater sense of scale and place, even the context - the lidar context - so that is something that we try to incorporate more but also augmented reality as well." (Al Rawlinson, Lyn Wilson)

This indicates the importance of exploring how virtual reality can be used with users and to test the degree of interactivity for the users in such experiences. Saddik also discusses how interactivity changes depending on the type of audience, noting that, within the same project, one can have several interactive applications to suit different types of audience:

"We have different scopes for different types of audience; a scope could be used for the researcher another scope could be used for the public. The public could include, for example, young people, and this could be in the form of games around thinking, for example a game matching the different types of columns with different eras, such as Doric columns, Ionic columns. They can be linked to be interpreted within the site virtually and the different kinds of reconstructions, and the user can then choose which one will be, for example, more suitable for that. This type of representation could be used for the public because for the public sometimes it can be more confusing than [for] experts." (Amira Saddik)

Other forms of interactivity which may also be found within augmented reality environments were mentioned by Rawlinson and Wilson and by Haynes:

"You can use location based augmented reality to view the forts, so the same fort that we have used for an educational game, we can reuse it in the app and we

> *can also use 3D models for the artefacts that were excavated, so VR is increasingly important in that context." (AL Rawlinson, Lyn Wilson)*

> *"I mean augmented reality is even more interesting here, you know, where people can actually visit the site to see what's there and then see how people have attempted to visualize its ancient appearance." (Ian Haynes)*

5.6.4 Visualization Techniques

As for visualization techniques for representing subjectivity within virtual reality environments, several of the experts agreed that the choice of one technique over another depends on several factors, notably the type of project and the type of audience.

Gration mentions several visualization techniques, including colour, patterns, and illusional effects where the separation between what is certain and what is uncertain dissolves at a distance:

> *"There are different techniques that people use; sometimes it is just with change in colour, sometimes it is more patterned coloured, sometimes we use tiny little lines, so, from a distance, it emerges as very nice and once you get closer you can clearly see the difference - that this is the artist and this is the reconstruction - and I think that could kind of really help within the digital sphere because you can have a really good view, but then, once you get closer, you see, Oh this is where certainty stops and the interpretation takes over." (Jonathan Gration)*

Rawlinson and Wilson, on the other hand, discuss choosing simple, non-photorealistic models when working on several interpretations:

> *"If we considered several interpretations, we would then probably create block models rather than photorealistic models in the first instance, which would be completely different to a photo textured or a photo realistic detailed model, which would be developed as potentially an end product." (Al Rawlinson, Lyn Wilson)*

They also highlight, once again, that the starting point in the decision-making process is the type of project and its aim and purpose, and these must be considered before taking any decisions concerning the methodology used, the visualization used, and the modelling technique.

> *"Again it depends on what is the objective of the reconstruction is and what a non-photorealistic version would be suitable for that purpose or if you would be*

> *needing something that is a lot more and potentially true to the original form of the archaeological site." (Al Rawlinson, Lyn Wilson)*

Gration also supports this by mentioning the importance of realizing the purpose of the project and making the decisions accordingly. He explains that projects that are for research purpose will be quite different than projects that target public engagement, and this would certainly have an impact on the choice of rendering and the visualization techniques chosen:

> *"I guess it would depend for what purpose the reconstruction is [created]. I've worked on reconstructions that are mainly to aid the process of the physical intervention or conservation treatment, and I've also worked on projects that were just for research and others that were specifically aimed at audience engagement. Probably the ones for research were much more documentation based, and they have a lot less of a specific requirement when it comes to the visualization that comes out of it, because they don't require a very specific type of look into reconstruction - they want you to be able to reconstruct what you think, so the representations of walls tend to be enough and adding the documentation of what you have on site, using laser scanning or photography records – so it is much more 'this is what there is' and how it relates to each other." (Jonathan Gration)*

5.7 A Theoretical Framework for Developing a Virtual Or Augmented Reality Model

In order to summarize the findings from this chapter a development of the theoretical framework created in the previous chapters was generated. The framework shows the process for developing a virtual or augmented reality experience model and includes a number of distinct phases.

The first phase, according to the discussions with the experts, would be defining the project aim in order to be able to determine the best approach and methodology to follow. The project aim could be for documentation, representation, and/or dissemination. When discussing the methodologies with the experts, it became clear other constraints also determine the chosen approach and technologies; these include the available evidence, the available budget, the project timeline, the target users and the skills of the experts involved. All of these factors were identified by the experts as being determinants of the final outcome in the form of a virtual reality model or application.

The next phase focuses on the different evidence types, namely archaeological evidence (on site or elsewhere in museums etc.), textual evidence, visual evidence, similar architecture, contextual comparisons, environmental context, survey data, architectural elements, previous reconstructions and function. These different types of evidence are collected and compared in order to reach consensus regarding how the building looked. However, some types of evidence are considered more reliable than others, and, based on the experts' opinions, these evidence types can be classified, from the most reliable to the least reliable as follows: survey data, archaeological remains on site, artefacts in museum collections, textual evidence, visual evidence, previous reconstructions, contextual comparisons, similar architecture, function and last environmental context.

Following the study of the available evidence, the next phase covers the decision making regarding the choice of technologies. With virtual reality experiences, the main two types of technologies to choose from are virtual reality and augmented reality. This is followed by a more detailed choice of technologies used for 3D documentation, 3D modelling, virtual reality programming and modelling and integrated modelling.

The final phase involves peer review and discussion and the creation of the final model. The experts mentioned that, prior to generating the final outcome for the users, several proposals are generated. Through peer review and discussions one proposal is then selected to be presented to the users. Several of the experts expressed concerns that presenting more than one model to the public users might generate confusion; therefore, they would only usually present multiple reconstructions to experts and within research work. If the project's target users are the general public, only one proposal is chosen as a final outcome. A copy of the framework is provided in Figure 5.16.

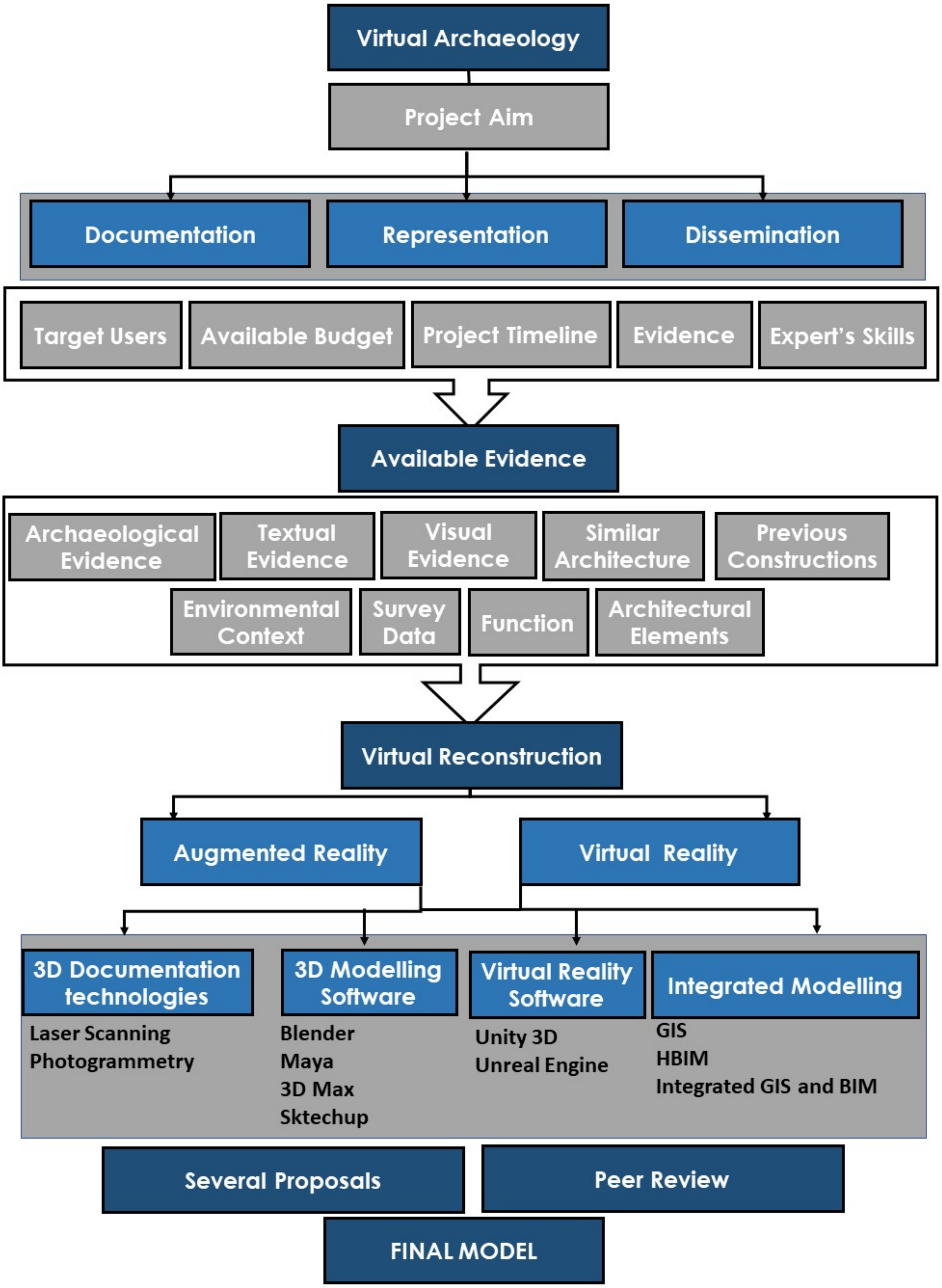


Figure 5.16: Virtual Model Framework developed from the theoretical findings and the expert interviews

5.8 Conclusion

This chapter has investigated how experts in the digital reconstruction of archaeological sites use digital technologies and, specifically, virtual reality in their work. It has also begun to consider how these could be applied to visualise the uncertainty in digital archaeological reconstructions. The first part of the analysis focused on the different types of evidence used in reconstructions and concluded that there are no specific types which are used in all projects as the evidence used in any project depend on the site itself and the availability of evidence. In general, all the experts agreed that they try to find as much evidence as possible and work on creating correlations between the different evidence types. However, there is a variance in the degree of reliability and importance of each type of evidence, with some considered more reliable than others.

The second part of the chapter explored the subjectivity of digital reconstructions through analysing the experts' use of terms related to subjectivity. The analysis reached a number of conclusions related to how the mental process of interpreting evidence and transferring it into models includes a large degree of subjectivity. The subjectivity arises from the human influence that is involved in the process, whether only one expert or a team of experts are involved. This underlines the importance of this research work and the need to conduct a case study to investigate how this subjectivity could be presented using virtual reality.

The third section considered a number of recommendations and applications for using virtual reality mentioned by the experts; however, not all of these applications would be used for the same project. The choice of which methodology and which approach to follow depends on the project's aims and purpose, and the intended audience for the final model. A merger between the different approaches is also a possibility, and a prototype will be applied in the following chapters to investigate how virtual reality could be used to visualise the subjectivity of digital archaeological reconstructions. The chapter has concluded by presenting a theoretical framework which shows the phases involved in developing a virtual or augmented reality experience model; this is based on the frameworks developed in previous chapters and the analysis of the expert interviews detailed in this chapter.

6. CHAPTER 6: THE LABYRINTH OF HAWARA IN-BETWEEN VIRTUALITY AND REALITY

6.1 Introduction

As previously discussed, uncertainty has always been part of archaeological interpretations, and the fact that archaeologists tend to try and generate an understanding of the meaning of objects in order to reach a definite meaning has been widely discussed in archaeological theories (Bonney et al. 2016). The previous chapters have explored the theoretical aspects of the uncertainty of digital archaeological reconstructions, with an in-depth investigation conducted by interviewing experts in the field. The interview analysis yielded a classification for the types of evidence used in digital archaeological reconstructions and several recommendations for virtualizing the uncertainty within them. In order to further validate these findings, a case study was conducted in order to create and apply a methodology for virtualizing the uncertainty of digital archaeological reconstructions. The site selected for the case study is the Egyptian Labyrinth known to be located at the site of the Hawara pyramid in Fayoum, Egypt (Uytterhoeven, Blom-Böer 2002). This site was chosen because it strongly reflects the uncertainty of archaeological interpretations: the Labyrinth of Hawara has been a mystery through history and has been reconstructed in various forms by numerous historians (NRIAG et al. 2008), making it highly suitable for virtualizing the uncertainty of digital archaeological reconstructions. This chapter provides a historical study of the case study site, examining previous textual, visual, and virtual reconstructions, from the earliest description by Herodotus to 21st century reconstructions using state-of-the-art technologies. In each case, it highlights the uncertainty inherent in each reconstruction, and concludes by developing a timeline of uncertainty to represent the gap between the reality of the Labyrinth and the way it has been represented. It also includes details of the field trips undertaken by the author to examine actual archaeological evidence from the site and compare that to the reconstructions. In exploring the Labyrinth in-between virtuality and reality, and in capturing digital images of the physical evidence, the chapter provides a basis for the creation of a prototype for virtualizing the uncertainty of digital archaeological reconstructions through a virtual reality experience, based on the case study, which is developed and explored in the following chapter.

The Egyptian Labyrinth, a mudbrick pyramid constructed during the reign of Amnemhat III, is the first structure in history to be named ‘Labyrinth’ by the Greek author Herodotus. The term “labyrinth”, also “maze”, is used to describe a network of blind passages arranged in such a way as to be difficult to navigate, and was first used by the Ancient Greeks and Romans to define a certain typology of buildings, often constructed below ground, which included a number of chambers and passages (Encyclopaedia Britannica 2014). Ancient Egyptian architecture did not typically include such typology, and the Egyptian Labyrinth, situated in the north of Egypt at Hawara in Fayoum, appears to be the only example. The Labyrinth itself was a huge building (Matthews 1970); however, the site now includes only scant evidence of the pyramid's existence. Among fragments and pieces of artefacts from different historic periods, a few fragments of columns and bricks remain, possibly from the Labyrinth and the Roman village constructed on the site during a later period of time. However, despite the lack of physical evidence, the site has been visualised numerous times during different historic periods, with multiple historians drawn to it by Herodotus' claim that it surpassed even the Pyramids in its greatness (Lloyd 1970). Petrie, in his documentation for his excavations of the site, mentioned that it seems impossible to reconstruct the Labyrinth as it was depending only upon the remains found (Petrie 1912); yet, he himself attempted to do just that by drawing a number of reconstructions of the site, and virtual reconstructions by researchers in the field of archaeology have been ongoing through history and into the 21st century (Shiode & Grajetzki 2019).

This chapter explores the visualizations and reconstructions generated for the Egyptian Labyrinth, questioning the reconstructions attempted, even those in the 21st century. The main aim is to discuss how the reconstruction of ancient architecture impacts our understanding of history, how it creates a definite view of the past, in a very rigid way, which may not benefit our understanding and may never have actually existed. As the research will show, the variation in the attempts that have been made to reconstruct the Labyrinth site, even centuries after it was totally destroyed, prove the subjectivity of these constructions; each of them have been influenced by the people involved, whether historians, architects or artist. They are all virtual and unreal in their own way; however researchers have often dealt with these descriptions as if they were relatively proven facts.

6.2 Reconstructing the Labyrinth at Hawara

The earliest "virtual" reconstruction of the Labyrinth came in the form of a written text by Herodotus (ca. 484-430 BC) (Herodotus 1988) which was the main reference for all the reconstruction attempts that followed. Other written texts describing the Labyrinth are also explored in this chapter, including those by Manetho (3rd Century BC), Diodorus Siculus (60-30 BC), Strabo (ca. 64 BC - AD 19), Pliny (AD 23-79), and Pomponius Mela (1st century AD). A number of visualization attempts are also analysed, namely those by Athanasius Kircher (1679), Luigi Canina (1795 -1856), The French Expedition (1809), The Prussian Expedition (Karl Lepsius – Richard Lepsius 1843-1845), Sir Flinders Petrie (1889-1890), and, most recently, recent research work by Narushige Shiode and Wolfram Grajetzki, (2000).

This chapter investigates how the Labyrinth was imagined by so many experts based on such little physical evidence. In doing so, it highlights how historical information could be misinterpreted and misrepresented to the public. Part of the aim of this research is to identify ways to provide further information to the users in order to make it clear that any attempt to reconstruct a historical site includes a certain degree of speculation. One possible way to achieve this is to generate a virtual reality experience which presents several reconstructions of the Labyrinth generated by experts while adding interactive media to explain who generated them and to give basic information regarding the approach they followed. In order to identify the most appropriate reconstructions to include in the virtual reality experience, it is important to examine both previous reconstructions and the evidence available from the site itself. The approach to collecting data was to collect as much data as possible. The following sections describe the different types of evidence collected from the archaeological site at Hawara in addition to other resources from libraries and previous researches related to the site. These different types of evidence are classified according to the classification generated in the previous chapters. This chapter therefore includes the evidence classification of the case study as well as investigating how the Labyrinth was imagined by so many experts with such minimal evidence.

6.3 Environmental Evidence, Landscape and Topography

The first type of evidence that was gathered regarding the Egyptian Labyrinth is environmental evidence. This includes the geographical location of the Labyrinth as well as the surrounding landscape and topography. The location of the Labyrinth right next to the Hawara Pyramid site was identified by Sir Flinders Petrie (Petrie 1912); however, this has been a matter of some dispute, as explained below. The site also currently suffers from an underground water problem (Keatings et al. 2007), the consequences of which are explored in the following sections.

6.3.1 *The Location of the Labyrinth*

The location of the Labyrinth is currently agreed to be at the Hawara pyramid complex in Fayoum (Petrie 1912); however this has long been a debatable point. While it was usually assumed to have been located at the entrance to Fayoum, some have suggested that it might have been located further to the side of Lake Qarun (also known as Lake Moeris). A number of ancient figures described the location after visiting the site, including Strabo, who clearly stated that he reached the Labyrinth after sailing about 30 to 40 stadia (a stadia is equivalent to 185 to 192 metres [607-630 ft]) into the canal. He also mentioned that Arisnoe was still 100 stadia ahead of the location of the Labyrinth. From this statement, it is clear that the Labyrinth lies between Fayoum and Arisnoe. Another statement by Herodotus states that the Labyrinth was located a little above Lake Moeris and close to a city that is named after the crocodiles. This description indicates that it cannot have been on the other side of the Fayoum oasis. In addition, all the authors mentioned that the Labyrinth was located next to a pyramid. Hawara is the only pyramid that fits this description, as it is located between the canal and Arisnoe; however, this does not match the distance suggested by Strabo. The real distance from the canal is 55 stadia, as opposed to the 30-40 stadia indicated by Strabo, and it is only 80 stadia from the canal to Arisnoe, rather than 100; therefore Strabo's distances would locate the site two or three miles to the east of the location of the Hawara pyramid. Despite this, when Petrie walked along the canal between Hawara and Ilahun, he found no evidence of any other buildings or pyramids except for those at Hawara. This is how he built his conclusion that there is no other site worth exploring in search of the Labyrinth apart from Hawara (Petrie 1889). The images below (See Figure 6.1) show the site today,

Figure 61.: Images from the site of the Hawara pyramid and labyrinth

with the remains of the mudbrick pyramid of Amenemhat III and some other remains that will be explained in detail in the following sections. The historical map below (See Figure 6.2) provides an overview of the location, showing with Lake Moeris, Crocodopolis, the supply canal Strabo mentions, and the site of Amenemhat III's pyramid.

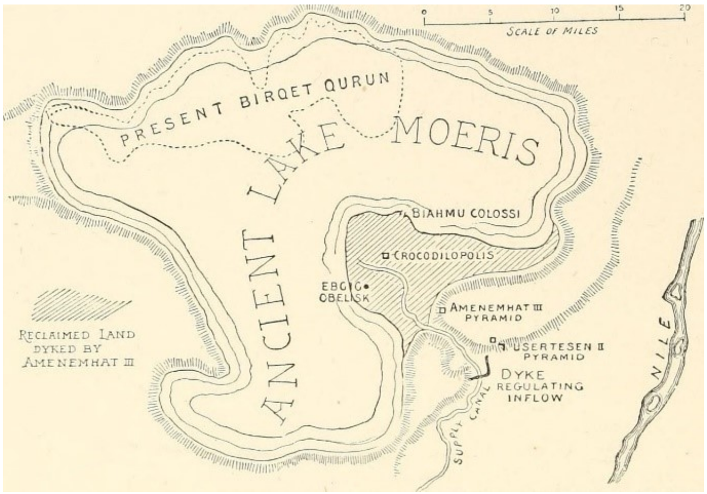
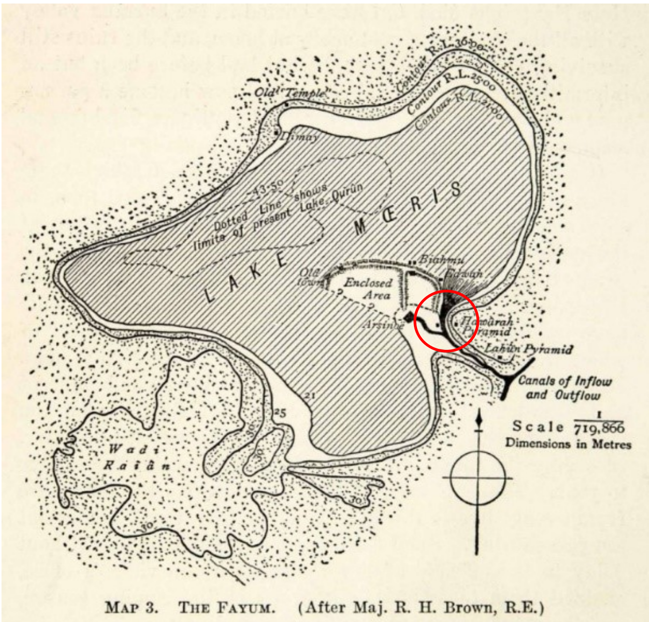


Figure 62.: A historical map of the location showing Lake Moeris, the supply canal, Crocodilopolis and the site of Amenemhat III's pyramid.
Source: https://en.wikipedia.org/wiki/Lake_Moeris#/media/File:Lake_Moeris.jpg

6.3.2 *Landscape and Topography*

The Labyrinth of Egypt was strongly linked to Lake Moeris in all the historical writings and, as in Figure 2, its location is indicated by reference to Lake Moeris in all the maps. Herodotus expressed great admiration in his writings for Lake Moeris, describing it as an artificial lake of a huge size, fed by water from the canal (now known as Behr Yusif). He also mentioned that there existed two pyramids overlooking the lake (Matthews 1970, p. 8). During the time of Herodotus, the lake seems to have been kept at its highest level, and, according to Petrie, no Greek archaeological remains were to be found in the area that covered the lake, which suggests that this theory is correct. As for the size of the lake, it was described by Herodotus as equal to the coast of Egypt, but Petrie claimed this was a huge exaggeration (Petrie 1889). Strabo who lived four centuries after Herodotus also mentions Lake Moeris and the Labyrinth in his work "Geography of the World", completed in the 20s AD. In his account about the lake from his own personal observation he mentions that it was used as a storage reservoir for water from the Nile (Matthews 1970, p.9).

During the time of the Persians and Ptolemies, the focus shifted to using the land around the lake for construction rather than expanding irrigation projects, and this caused the inflow to be restricted, leading to the gradual drying up of the lake. During the time of the Romans, the lake was much reduced, as indicated by the construction of several Roman towns below Nile level, including Kasr Karun on the shore of Lake Garun (at 72 feet below Nile level) and Dimeh (at 69 feet below Nile level), the latter with a quay at about 87 feet below the Nile (Petrie 1889) The maps below show Lake Moeris and what is now the city of Fayoum, surrounded by mostly agricultural land. The location of the Hawara pyramid and the Labyrinth is clearly indicated (See Figures 6.3, 6.4 and 6.5).



MAP 3. THE FAYUM. (After Maj. R. H. Brown, R.E.)

Figure 6.3: Historical map of Lake Moeris
Source: https://fayoumegypt.com/about-fayoum/

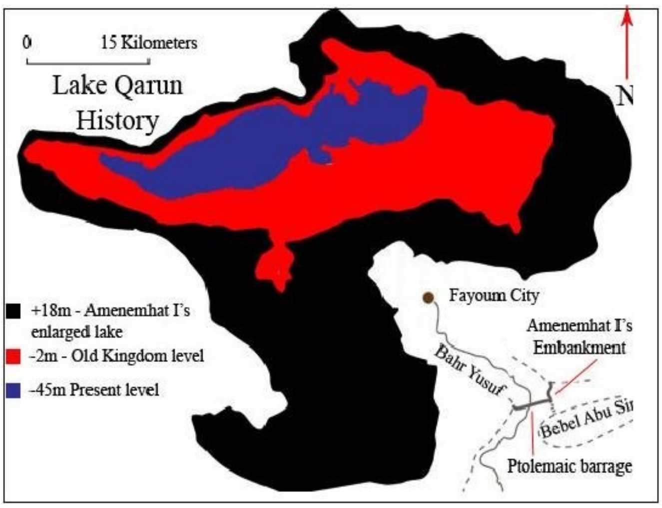


Figure 6.4: Historical development of Lake Meoris. Source: Mosalam Shaltout, Mohamed Azzazi in their research (Palaeobotanical Study on Soil Strata of Lake Qarun Shore since Helleno-Roman Period https://www.researchgate.net/publication/276409159_Palaeobotanical_Study_on_Soil_Strata_of_Lake_Qarun_Shore_since_Helleno-Roman_Period/figures?lo=1&utm_source=google&utm_medium=organic)

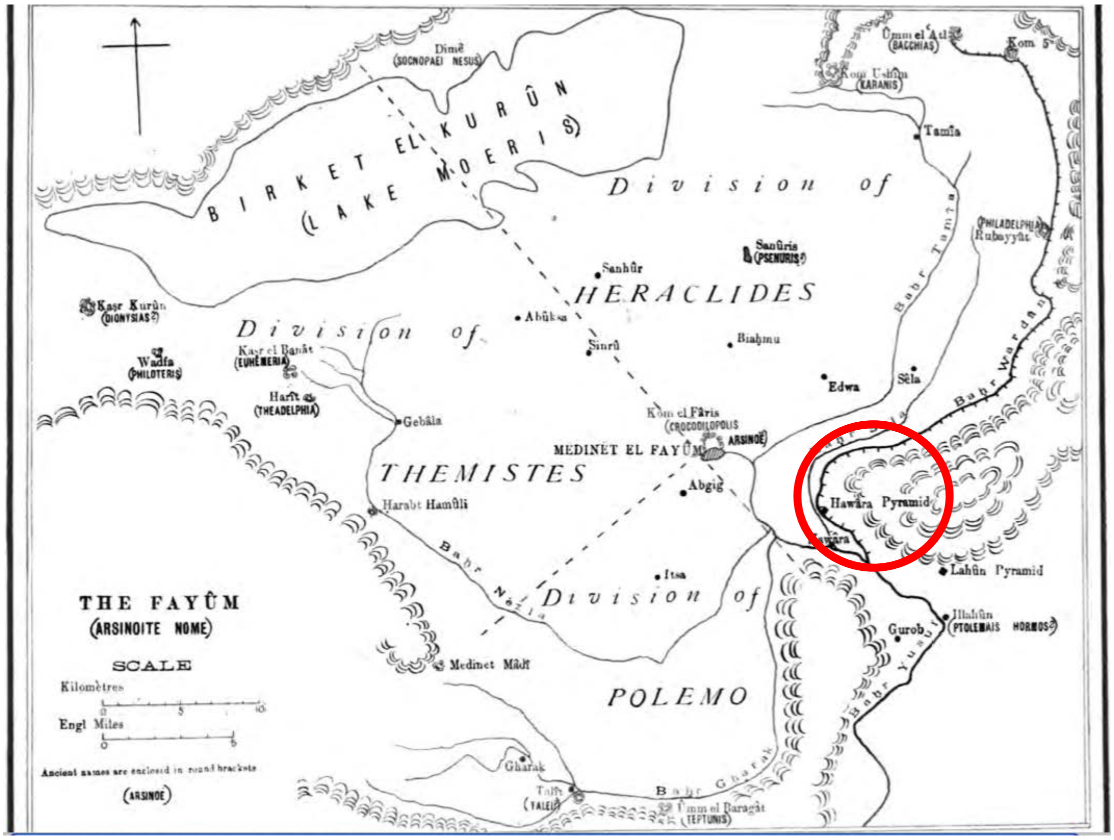


Figure 65.: Map of Fayoum from 1895 clearly showing the location of the pyramid at Hawara. Source: https://en.wikipedia.org/wiki/File:Karanis1.png

6.4 Textual Evidence

The second type of evidence studied within this case study application is textual evidence. The textual evidence about the Labyrinth of Egypt was one of the most important types of evidence as it was the base for other reconstructions that were generated in later periods. The following sections explore key texts by a number of Greek and Roman authors, including Herodotus and Strabo.

6.4.1 *Early Accounts by Greek and Roman Authors*

The first accounts of the Egyptian Labyrinth came to us through texts written by Greek and Roman historians as part of their narratives of their trips to Egypt. As previously mentioned, Herodotus wrote about a great Egyptian labyrinth located on a great lake, close to a city named after the crocodiles, and Strabo, Diodorus Siculus, Pliny the Elder, Manethon, and others, also mentioned the Labyrinth in their writings (Matthews 1970) There are six written accounts of the Labyrinth that were collected and translated by Alan B. Lloyd. He also arranged them in chronological order. His work has been identified as the most comprehensive in collecting all the written texts about the Labyrinth (Lloyd 1970), and it provides a basis for the discussion here. As Lloyd records, the first account of the Labyrinth that we received from history was through the Greek historian Herodotus, and this formed the base and main resource for most of the visualizations made of the Labyrinth. However, this raises the essential question of how much one could rely on a single text written by one single person describing the site. The following section provides a brief background details about Herodotus and his trip to Egypt and the translation of the text he included in his books about the Labyrinth, then goes on to examine his descriptions in detail.

6.4.1.1 Herodotus (Ca. 484-430 BC): One Passage in Histories, Book II, 148.

Herodotus is a Greek historian who is believed to have been born in Halicarnassus in around 484 BCE (Encyclopaedia Britannica 2019). Known as the “Father of History”, Herodotus lived for much of his life in Athens, but also travelled extensively around the ancient world (Matthews 1970). His writings indicate that he visited Egypt, Libya, Syria, Babylonia, Susa in Elam, Lydia and Phrygia, and he also travelled north to Hellespont and from there to Byzantium, Thrace, Macedonia, Danube, Scythia and the Black Sea. It probably took a large number of years in order to be able to take up these journeys (Encyclopaedia Britannica 2019)

His written work in the original Greek language is fresh, simple and in great harmony. However, this should not be considered as a valid resource for those seeking accurate reliable historical information. There is no question that Herodotus’ writings had a poetic nature rather than striving for historic accuracy, and this should be taken into consideration; however, according to Matthews, there is no direct reason to consider his accounts to be exaggerated (Matthews 1970). These doubts are very much in evidence in relation to Herodotus's Egyptian travels, and there are multiple opinions about the accuracy of his accounts, with some research suggesting they include a degree of speculation. (Encyclopedia Britannica 2019) His trip to Egypt was probably not long enough to establish as detailed an account as his writings present, and it was more likely the case that he travelled to Egypt to clarify some missing points in the ancient literature that he read. He had an advantage in that Greeks had been living in Egypt for around 200 years at the time, so he was able to communicate easily; however, he did not know the language of ancient Egyptians so he relied on oral narratives by either expatriate Greeks or Greek-speaking Egyptians. Unable to read ancient Egyptian, he also relied heavily on local guides (cicerones) for translations of the inscriptions on the temples, and these may not always have been accurate. According to Herodotus, he also met responsible temple officials on some occasions; however, communication with them was quite difficult, relying either on the integrity of the interpreter or the official's alleged knowledge of Greek. As Brown points out, this being the situation, Herodotus tended to phrase questions in the format that gave the answers he was expecting, and the guides, perhaps hoping to get extra fees, were keen to oblige his wishes (Brown 1965).

With these reservations in mind, a detailed account of the Labyrinth has come to us from Herodotus (Matthews 1970). He wrote about vising a great Egyptian Labyrinth located on a great lake near the city of the crocodiles, now known as Fayoum, (Armayor 1985) and claimed to have visited the Labyrinth itself, recording that he entered the 1500 chambers in the upper storey but was not allowed to enter the 1500 underground chambers. (Translated from Herodotus II p.148, as given in Lloyd 1970) He also mentions that it was located right above Lake Moeris; however scholars have questioned whether he ever actually visited the lake (Armayor 1985). The following is a translation of part of the description of the Labyrinth written by Herodotus, taken from the second book of his History. Given its significance to subsequent reconstructions, the text is quoted at length:

> *"Moreover, they decided to leave to posterity a common memorial and caused to be built a Labyrinth for their greater glory, a little above Lake Moeris more or less in the vicinity of the city called the City of Crocodiles; this Labyrinth I actually saw, a work greater than all power to describe. For if anyone were to add together the buildings constructed by Greeks and their architectural achievements, they would appear inferior in labour and expense to this Labyrinth. Yet both the temple at Ephesus and that at Samos are by no means negligible. Indeed, the Pyramids also surpassed all power to describe and each one of them was comparable to many great works of the Greeks, but the Labyrinth – it surpasses even the Pyramids.*

For it consists of twelve roofed courts which have their gates opposite one another, six facing northwards and six facing south. The courts are also contiguous, and are confined by the same wall on the outside. Inside are two groups of chambers, one group underground, the other group above on top of them, 3,000 in number, 1,500 of each type. The chambers above ground I myself saw as I passed through them, and I speak of them on the basis of my own observation, but the subterranean group I heard of only by oral report. For the Egyptians in charge refused flatly to show them, saying that there lay the tombs, not only of the kings who had caused the Labyrinth to be built in the beginning, but also those of the sacred crocodiles. So my statements on the lower chambers are based on hearsay, though I speak of the upper chambers from my own observation.

These upper chambers are quite beyond human capacity to build; for both the exits through the vestibules' and the extremely twisting and winding course which one must take through the courts inspired boundless wonder as one passed from court into chambers and from chambers into columned porches, then into further vestibules from the columned porches and into yet other courts from the chambers. All these structures have a roof made of stone – exactly like the walls, and the walls are covered with reliefs, and each court has a colonnade around it made of exactly fitting limestone blocks. Adjacent to the corner at the end of the Labyrinth stands a pyramid 40 orguiae high on which mighty figures are carved; and a subterranean passage runs into."

(Translated from Herodotus, Histories II p. 148, as given in Lloyd 1970)

Herodotus began by describing how the Egyptians divided the land into 12 parts, known as 'nomes', with a different king responsible for each nome; however, they then agreed to work together to create a memorial for themselves, and so the Labyrinth, located above Lake Moeris and opposite Crocodilopolis (the City of Crocodiles), was constructed. "I found it," he says, "greater than words could tell", yet he goes on to provide a detailed description of 12 peristyle courts surrounded by a wall, six facing north and six facing south, with the doors facing each other. However, Petrie clarifies that this description relates only to a section of the Labyrinth, most probably the part near to the entrance (Petrie 1889). Herodotus also states that he was only allowed to access the upper rooms as the lower rooms were considered sacred so were not accessible for visitors. It is well known that there were restricted areas in Ancient Egyptian temples so he was probably allowed to enter only a part of the building (Matthews 1970); however, these chambers were clearly the most dominant part of the building to have caught his attention (Petrie 1889). The upper rooms are described as being massive in scale with a complex system of passages, courts, rooms and colonnades. The roof of the Labyrinth was made of stone, the walls were engraved, and a number of white stone columns surrounded the courtyards. Just outside the Labyrinth, on its corner a pyramid of 40 orguiae (about 240 feet) was constructed, which Herodotus described as being covered with huge carved figures.

The description Herodotus gives of the Labyrinth is clear in terms of describing the main distribution of spaces and the number of courts and chambers. He also describes details such as the colonnades and the engravings and reliefs on the walls. This early written description became the main reference for later historians who described the Labyrinth, through texts as well as visuals, such as images and plans (Matthews 1970. However, the question remains as to whether this description would be sufficient to attempt a reconstruction of the Labyrinth. Given that no other authors, historians, artists, architects and archaeologists who visualized the Labyrinth were able to visit the site in its complete state, there is no clear proof of the architectural design of the Labyrinth to contradict it. However, this description is quite different from the other known building typologies in Ancient Egyptian architecture, raising further questions about its reliability. The following sections explore other textual and visual reconstructions of the Labyrinth throughout history, noting the similarities or divergences from the descriptions Herodotus gives, and highlighting the uncertainty within them.

6.4.1.2 Manetho (3rd Century BC): Short Fragment from His List of Egyptian Kings.

Manetho was an Egyptian priest known for documenting the succession of Ancient Egyptian kings in the Greek language. This documentation is believed to have been commissioned by Ptolemy II Philadelphus and is thought to be based on primary resources that were either oral or written (Encyclopaedia Britannica 2016a). Manetho was probably one of the few authors who actually visited the site; however his work did not provide a description of the architectural design of the Labyrinth but rather confirmed its function. The following is the text he included in his work about the Labyrinth:

> *"Fourth King. Lamares, eight years. He built the Labyrinth in the Arsinoite Nome as a tomb for himself. Manetho"* (The Petrie Museum of Egyptian Archaeology, 2000)

The significance of this fragment of is in stating that the Labyrinth was built as a tomb. The description provided by Herodotus suggests it was a building for worship, as it includes a huge number of courtyards and chambers; however, the typical case in Ancient Egyptian pyramids is that they would be associated with funerary temples to serve the burial of the king.(Siliotti 1997) This was probably the case for the Labyrinth as well, and that might explain why Manetho describes it in his text as a tomb for the king.

6.4.1.3 Diodorus Siculus (1st Century BC): Two Passages in His History, Book I, 61 and 66.

Diodorus Siculus is a Greek historian who lived in the time of Julius Caesar and Augustus, and his work shows that he visited Egypt in the period between 60-57 BC. (Encyclopaedia Britannica 2018) He wrote about the Labyrinth and Lake Moeris in a long text called the “Historical Library”, which explains that the lake was constructed by King Moeris. According to Diodorus Siculus, King Moeris built a sepulchre and two pyramids in the middle of the lake, one for himself and the other for his queen, surmounted by huge seated statues (Matthews 1970). The following text is the description of the Labyrinth written by Diodorus Siculus, explaining how and why it was created:

> *"When the king died the government was recovered by Egyptians and they appointed a native king Mendes, whom some call Mares. Although he was responsible for no military achievements whatsoever, he did build himself what is called the Labyrinth as a tomb, an edifice which is wonderful not so much for its size as for the inimitable skill with which it was build; for once in, it is impossible to find one's way out again without difficulty, unless one lights upon a guide who is perfectly acquainted with it. It is even said by some that Daedalus crossed over to Egypt and, in wonder at the skill shown in the building, built for Minos, King of Crete, a Labyrinth like that in Egypt, in which, so the tales goes, the creature called the Minotaur was kept. Be that as it may, the Cretan Labyrinth has completely disappeared, either through the destruction wrought by some ruler or through the ravages of time; but the Egyptian Labyrinth remains absolutely perfect in its entire construction down to my time."*

> *"And seized with enthusiasm for this enterprise they strove eagerly to surpass all their predecessors in the seize of their building. For they chose a site beside the channel leading into Lake Moeris in Libya and there constructed their tomb of the finest stone, laying down an oblong as the shape and a stade as the size of each side, while in respect of carving and other works of craftsmanship they left no room for their successors to surpass them. For, when one had entered the sacred enclosure, one found a temple surrounded by columns, 40 to each side, and this building had a roof made of a single stone, carved with panels and richly adorned with excellent paintings. It contained memorials of the homeland of each of the kings as well as of the temples and sacrifices carried out in it, all skillfully worked in paintings of the greatest beauty. Generally it is said that the king conceived their tomb on such an expensive and prodigious scale that if they had not been deposed*

before its completion, they would not have been able to give their successors any opportunity to surpass them in architectural feats." (Lloyd 1970)

The account provided by Diodorus Siculus is very similar to that of Herodotus (Petrie 1889), and caution is required in the case of Diodorus Siculus too. He visited Egypt as a tourist and he is not believed to have carefully examined the written texts of the Priests of Egypt; nor did he take into consideration the authoritative history of ancient Egypt created by Manetho, even though it was written in the Greek language. (Africa 1963)

6.4.1.4 Strabo (Ca. 64 BC - AD 19): Three Passages in His Geography, Book 17, I, 3 and 37 and 42.

Strabo provides more details regarding the description of the Labyrinth when compared to the texts written by Herodorus and Diodorus Siculus. In addition to the courts, he writes about intricate passages that lead to the entrances of the courts, and he also describes a huge hall having 27 columns that was connected to the courts (Petrie 1889). The following paragraphs present a translation of part of the detailed description of the Labyrinth and its surroundings written by Strabo.

"the total number of nomes *was equal to the number of the courts in the Labyrinth; these are fewer than 30.*

In addition to these things there is the edifice of the Labyrinth which is a building quite equal to the Pyramids and nearby the tomb of the king who built the Labyrinth. There is at the point where one first enters the channel, about 30 or 40 stades *along the way, a flat trapezium-shaped site which contains both a village and a great palace made up of many palaces equal in number to that of the* nomes *in former times; for such is the number of peristyle courts which lie contiguous with one another, all in one row and backing on one wall, as though one had a long wall with the courts lying before it, and the passages into the courts lie opposite the wall. Before the entrances there lie what might be called hidden chambers which are long and many in number and have paths running through one another which twist and turn, so that no one can enter or leave any court without a guide. And the wonder of it is the roofs of each chambers are made of single stones and the width of the hidden chambers is spanned in the same way by monolithic beams of outstanding size; for nowhere is wood or any other material included. And if one mounts onto the roof, at no great height because the building has only one storey, it is possible to get a view of a plain of masonry made of such stones, and, if one drops back down from there into the* *courts, it is possible to see them lying there in row each supported be 27 monolithic pillars; the walls too are made up in stones of no less a size.*

At the end of this building, which occupies an area of more than a stade*, stands the tomb, a pyramid on an oblong base, each side about 4 "*plethra*" in length and the height about the same; the name of the man buried there was Imandes. The reason for making the courts so many is said to be the fact that it was customary for all* nomes *to gather there according to rank with their own priests and priestesses, for the purpose of sacrifice, divine-offering, and judgement on the most important matters. And each of the* nomes *was lodged in the court appointed to it.*

And above this city stands Abydos, in which there is the Memnonium, a palace wonderfully constructed of massive stonework in the same way as we have said the Labyrinth was built, though the Memnonium differs in being simple in structure." (Lloyd 1970)

Strabo mentions that the Labyrinth was "a work equal to the pyramids", and notes that it was a massive building that included halls equal to the number of *nomes* in ancient Egypt before the time of the labyrinth's construction (Matthews 1970) A *nome* is an administrative division in ancient Egypt, and the number of *nomes* increased throughout the history of ancient Egypt, from the old kingdom to the new kingdom (Encyclopaedia Britannica 2013) The halls include an equal number of courts and these are surrounded by columns, with the courts aligned and surrounded by a colonnade with 27 massive stone columns made of. According to Strabo, these courts are all linked to each other, forming the whole structure of the Labyrinth, and surrounded by a long wall and intertwined covered passages, creating a maze-like effect. Strabo even describes the roof as slabs of stone with no other materials used. Strabo also mentions a pyramid located at the end of the Labyrinth where the pharaoh Amenemhat III is believed to be buried. He even mentions the name of Imandes who designed the Labyrinth for Amenemhat III.

Strabo later comments on Herodotus saying that he was a merchant travelling to Egypt for trade, a description that suggests Strabo does not consider his accounts of the Labyrinth to be reliable. However, there are some similarities between both descriptions (Matthews 1970), and, again, caution about their validity may be needed. Indeed, previous research suggests that Strabo's account of the Labyrinth was probably based on previous narratives of Egypt rather than his alleged visits to Crocodilopolis, Fayoum, and the Labyrinth itself (Armayor 1985).

6.4.1.5 Pliny (AD 23-79): One Passage in His Natural History, Book 36, 13.

Pliny the Elder was a Roman author, a naturalist, and a nature philosopher, who mentioned the Labyrinth in his book "Natural History" (Stannard 2021). The book covers numerous labyrinths, and Pliny describes them as the most outstanding structures that men have built throughout history. He provides a detailed account of the Labyrinth, the reasons for its construction, and the materials used, as can be seen in the following translation of his description:

> *"Let us speak also of labyrinths, quite the most extraordinary works on which men have spent their money, but not, as may be thought, figments of the imagination. There still exists even now in Egypt in the Heracleopolite Nome the one which was built first, according to tradition 3,600 years ago by king Petesuchis or Tithois, though Herodotus ascribes the whole work to Twelve Kings and Psammetichus, the latest of them. Various reasons are given for building it. Demoteles claims that it was the palace of Moteris, Lyceas the tomb of Moeris, but the majority of writers take the view that it was built as a temple to the Sun, and this is generally accepted. At any rate, that Daedalus used this as the model for the Labyrinth which he built in Crete is beyond doubt, but it is equally clear that he imitated only 100th part of it which contains twisting paths and passages which advance and retreat - all impossible to negotiate. The reason for this is not that within a small compass it involves one in mile upon mile of walking, as we see in tessellated floors or the displays given by boys on the Campus, but that frequently doors are buried in it to beguile the visitor into going forward and then force him to return into the same winding paths. This was the second to be built after the Egyptian Labyrinth, the third being in Lemnos and the fourth in Italy, all roofed with vaults of polished stone, though the Egyptian specimen, to my considerable astonishment, has its entrance and columns made of Parian marble, while the rest is of Aswan granite, such masses being put together as time itself cannot dissolve even with the help of the Heracleopolitans; for they have regarded the building with extraordinary hatred."*

> *"It would be impossible to describe in detail the layout of that building and its individual parts, since it is divided into regions and administrative districts which are called* nomes*, each of the 12* nomes *giving its names to one of the houses. A further reason is the fact that it also contains temples of all the gods of Egypt while, in addition, Nemesis placed in the building's 40 chapels many pyramids of 40 ells, each covering an area of 6 arourae with their base. Men are already weary with travelling*

when they reach that bewildering maze of paths; indeed, there are also lofty upper rooms reached by ramps and porticoes from which one descends on stairways which have 90 steps each; inside are columns of imperial porphyry, images of the gods, statues of kings and representations of monsters. Certain of the halls are arranged in such way that as one throws open the door there arises within a fearful noise of thunder; moreover one passes through most of them in darkness. There are again other massive buildings outside the wall of the Labyrinth; they call them "the Wing". Then there are other subterranean chambers made by excavating galleries in the soil. One person only has done any repairs there - and they were few in number. He was Chaermon, the eunuch of king Necthebis, 500 years before Alexander the Great. A tradition is also current that he supported the roofs with beams of acacia wood boiled in oil, until squared stones could be raised up into the vaults." (Lloyd 1970)

Pliny states that it would be difficult to give full details about the whole Labyrinth due to its massiveness, but provides details of its appearance and the materials used in its construction, including the stone roof, entrance doors of Parian marble and Syenite columns. He describes it as a massive structure that will not be destroyed easily with time, but notes that it has been partially damaged by the people of Heracleopolites (or Beni Suef) as they have always hated it. Like Herodotus and Strabo, he describes the Labyrinth as divided into zones called '*nomes',* but claims there were 30 of these, in contrast to the numbers given by other writers. According to Pliny, each *nome* included a palace as well as a temple, and there were also temples for all the gods and goddesses of Egypt as well as 40 statues of the Greek goddess Nemesis. In addition to this, the Labyrinth includes several pyramids, raised festive halls reached by ramps, colonnades with 90 steps, columns made of porphyritic granite, and statues of gods, kings and monsters. Pliny even speaks of the terrifying sound that the doors of the palaces make and also about the Labyrinth being very dark. In addition to the Labyrinth, he writes about the buildings that surrounded it, including passages that lead to subterranean palaces.

Pliny claims that the Labyrinth still existed during his time, and that it was located in the *nome* "Heraclepolites", now in the city of Beni Suef. This is a different location than that indicated by authors such as Herodotus, who located it in the *nome* "Crocodilopolis", now the city of Fayoum. However, Pliny was not very always clear in his descriptions. For example, he states that the Labyrinth was first built 3600 years before his time by king Petesuchis or Tithoes. Petesuchis is the Greek name for "Ptah", the Ancient Egyptian god of creating things or the 'Maker' (Encyclopaedia Britannica 2020a); however, it is unclear whether he meant that the god Ptah was associated with the Labyrinth as he then mentions Herodotus' description, which indicated that the Labyrinth was instead built by 12 kings, the last of whom was Psmatic, known in Greek as "Psammetichus". Furthermore, other authors have stated that the last king was called "Moiris" or "Amenemhat III", and some historians have claimed that the Labyrinth was dedicated to the sun-god "Ra". The link between the Labyrinth and Amenemhat III is most widely accepted by historians, and this therefore contradicts Pliny's claims (Matthews 1970).

6.4.1.6 Pomponius Mela (1st Century AD): One Passage in His Chorographia, Book I, 9, 56.

Pomponius Mela, a Roman author, described the Labyrinth is his book *"De Situ Orbit"* (A Description of the World) also known as "*De Chorographia*" (Concerning Chorography), the only surviving treatise on geography written in the Latin language (Encyclopaedia Britannica 2016b). He describes it in the following words:

> *"The building of Psammetich, the Labyrinth, includes within the circuit of one unbroken wall 1000 houses and 12 palaces, and is built of marble as well as being roofed with the same material. It has one descending way into it, and contains within almost innumerable paths, which have many convolutions twisting hither and thither. These paths, however, cause great perplexity both because of their continual winding and because of their porticoes, which often reverse their direction, continually running through one circle after another and continually turning and retracing their steps as far as they have gone forwards with the result that the Labyrinth is fraught with confusion by reason of its perpetual meandering, though it is possible to extricate oneself."* (Lloyd 1970)

Although this description provides some details about the structure, it is thought that Pomponius Mela based his account on previous authors, such as Pliny the Elder, rather than his own first-hand experience (Matthews 1970).

6.5 Visual Evidence & Previous Reconstructions

In addition to textual descriptions of the Labyrinth, several historians attempted to generate reconstructions of it. Most of these were based on the previous textual descriptions, as well as some general knowledge about Ancient Egyptian architectural elements, and were, in many cases, artistic and rather visual. The sections below therefore consider textual accounts produced after the Greek and Roman periods well as the visual evidence they helped to inform. These cover a period of around 200 years, from Athanasius Kircher's reconstruction of 1679 to Karl Richard Lepsius's drawings in 1843.

6.5.1 Virtual Reconstructions *of the Labyrinth* During the Renaissance

The earliest reconstructions were mostly two dimensional and in the form of the layout, with some indication of how the elevations might have looked. Two of the earliest examples from the Renaissance are examined below.

6.5.1.1 A Plan of the Labyrinth by Athanasius Kircher

Athanasius Kircher, a German Jesuit priest and scholar, is believed to be the first scholar to provide a visual reconstruction of the Labyrinth. The copperplate engraving in his book "Turris Babel" (as shown in Figure 6.6) represents the Labyrinth as a square shaped structure with a maze in the middle, providing a visual translation of the ancient texts (Kircher 1679).

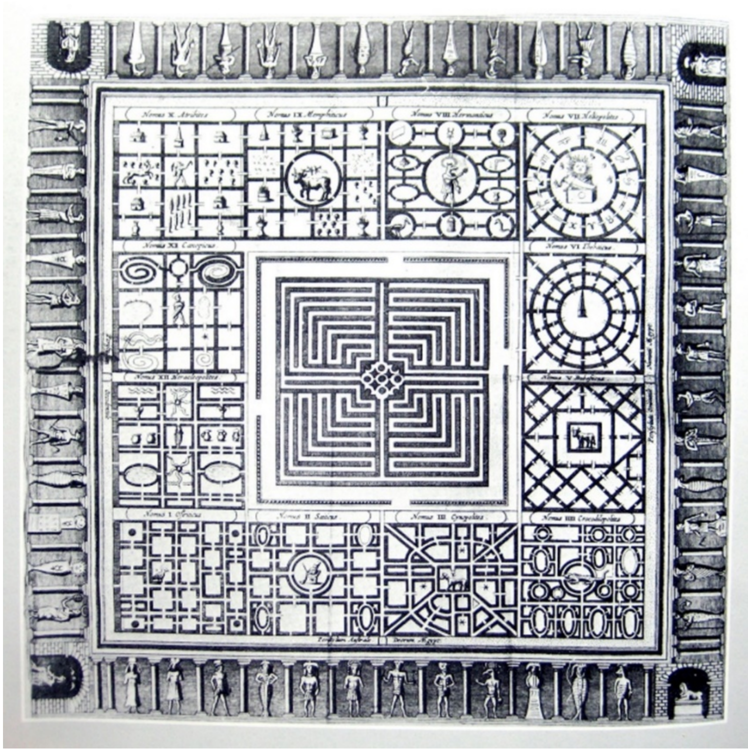


Figure 6.6: Reconstruction of the Egyptian Labyrinth by Athanasius Kircher. Copperplate engraving (50X 41 cm) "Turris Babel Sive Archontologia", Amsterdam 1679. Source: https://issuu.com/yago1/docs/labyrinth_of_egypt_com__hawra_2015

The visualization created by Kircher shows the maze surrounded by 12 courts; these are the 12 *nomes* described by Herodotus, each representing a territorial division of ancient Egypt. According to the labels Kircher included, the *nomes* were divided as follows: 1) Nomus I Ofuriticus, 2) Nomus II Saiticus, 3, Nomus III Cynopolites, 4) Nomus IIII, 5) Nomus V Bubalticus, 6) Nomus VI Thebaicus, 7) Nomus VII Heliopolites, 8) Nomus VIII Hermonticus, 9) Nomus IX Memphiticus, 10) Nomus X Atribites, 11) Nomus XI Canopicus, and 12) Nomus XII Heracleopolites.

6.5.1.2 An Alternative Plan by Canina

Like Kircher, many others have attempted to visualize the Labyrinth during the time of Herodotus. One such reconstruction was created by the Italian archaeologist Canina (See Figure 67.). Canina also divided the Labyrinth into 12 courts representing the 12 nomes, but he presented them as being symmetrical.

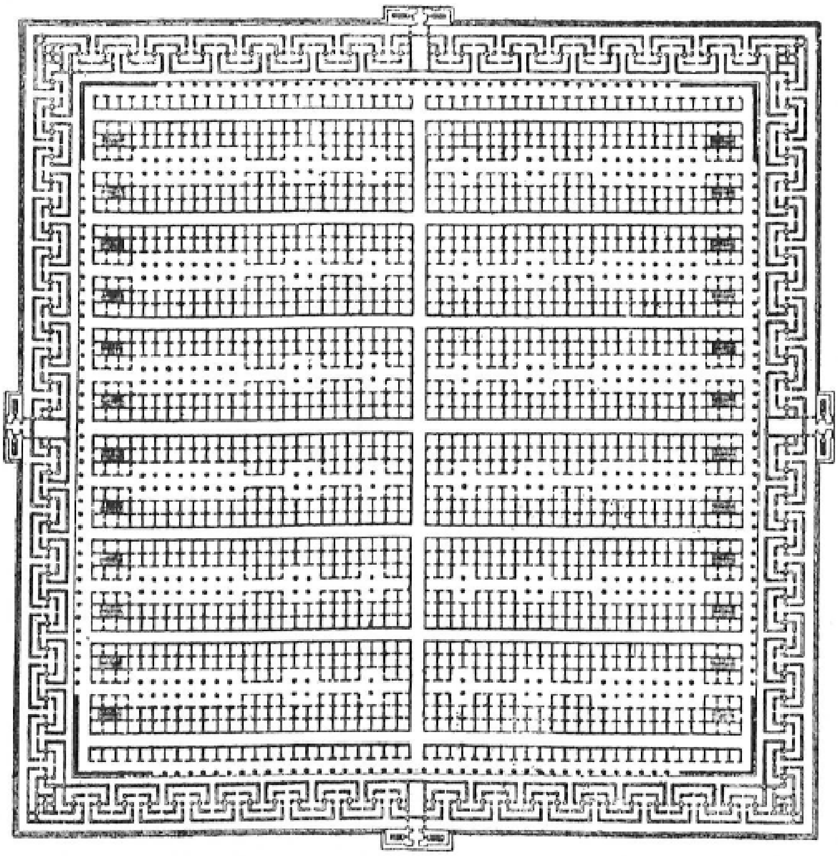


Figure 67.: Egyptian Labyrinth Restored Plan Source: Canina

https://www.researchgate.net/publication/308793995_Understanding_Wayfinding_Behaviours_Spatial_Orientation_and_Cognitive_Mapping__Book_Review_of_Wayfinding_Behaviour_Cognitive_Mapping_and_other_Spatial_Processes_by_Reginald_G_Golledge/figures?lo=1&utm_source=google&utm_medium=organic

However, the remains found by Petrie indicate that the original plan of the Labyrinth was not like this visualization by Canina (Matthews 1970). Petrie generated a very different reconstruction of the Labyrinth based on the descriptions by Herodotus and Strabo, and this is examined in Section 6.6 below.

6.5.2 *Accounts of the Egyptian Labyrinth by Later Explorers*

The Labyrinth remained a point of interest to later explorers; however, no serious attempts to locate it were made until several centuries later. Unfortunately, very few physical remains were left, as the Labyrinth was largely destroyed during the Roman period, and a village was constructed on the site using its remains. In addition, by that time, Egyptians themselves knew nothing about the Labyrinth in

Fayoum, or anywhere else, so the only information about it came from various historians, explorers, and archaeologists (Armayor 1985).

6.5.2.1 A Description of an Underground Labyrinth by Gamelli Careri

One of the later explorers who is thought to have visited the site, in 1693, is Gemelli-Careri,. He described visiting an underground labyrinth in the neighbourhood of the two pyramids, and the English translation of his account creates a vivid picture:

> *"The Arabs conducted us to see a Labyrinth, where the Ancients bury'd Birds. We went down a narrow Passage into a Room out of which we crept on our Bellies through a Hole to certain ways where a man may walk well enough upright. On both sides of these there are Urns, in which the Birds were bury' d; there is now nothing in them but a little dust. These Ways are cut out of a nitrous Stone and run several miles like a City underground, which they call a Labyrinth."* (Matthews 1970)

However, although these words are highly evocative, there is no clear proof that this description relates directly to the Egyptian Labyrinth .

6.5.2.2 Visual Documentation of the Remains by Paul Lucas

Paul Lucas, the Antiquary to Louis XIV, travelled to Egypt in 1700 and claims to have visited the Labyrinth site; however, his description of the remains is considered incoherent and unreliable (Matthews 1970). Lucas writes that he was accompanied by an Arab when he visited the site, who claimed to have explored the inner chambers of the ruins before and passed through the underground passages into a huge chamber surrounded by several niches, “like little shops,” connected to numerous alleys and rooms. Error! Reference source not found. shows a plan of the Labyrinth by

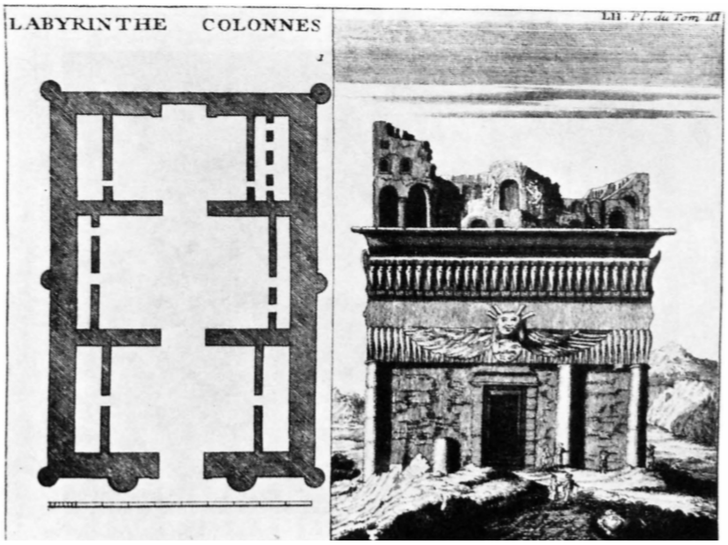


Figure 68.: Visual documentation of the Egyptian Labyrinth by Paul Lucas Source: https://www.sacred-texts.com/etc/ml/ml06.htm

Lucas, based on his companion's account, and a drawing of the alleged ruins; however, Lucas found no trace of the passages and he concluded that they had become blocked by the ruins (Matthews 1970) .

6.5.2.3 An Account of the Labyrinth Site by Richard Pococke

Dr. Richard Pococke was the next explorer to visit the site, and he included a description in his published work "Description of the East" in 1743. He describes what he calls "the temple of the Labyrinth" as a great building, with a length of 165 feet by 80 feet broad, now in ruins, and known locally as the "Castle of Caroon":

> *"We observed at a great distance," he says, "the temple of the Labyrinth, and being about a league from it, I observed several heaps of ruins, covered with sand, and many stones all round as if there had been some great building there; they call it the town of Caroon (Bellet Caroon). It seemed to have been of a considerable breadth from east to west, and the buildings extended on each side towards the north to the Lake Moeris and the temple. This without doubt is the spot of the famous Labyrinth which Herodotus says was built by the 12 kings of Egypt."* (Matthews 1970)

6.5.3 *Visual Reconstructions of the Site by The French and Prussian Expeditions*

The area was also explored during the French expedition sent by Napoleon Bonaparte by the end of the 18th century, and Jomard, one of the archaeologists on the expedition, claimed to have found the site of the lost labyrinth and its ruins (Matthews 1970). A similar claim was made by Karl Richard Lepsius, a German Egyptologist, who led a scientific expedition to Egypt and the Sudan from 1843 to 1845 under the patronage of Frederick William IV of Prussia. (Encyclopaedia Britannica 2020b). The evidence provided by these expeditions is discussed below.

6.5.3.1 The French Expedition

Travellers in the 17th and 18th century searched for the Labyrinth all over Fayoum as part of their search for Lake Moeris; however, the French expedition was the first commission to settle on Hawara as a possible site during the 19th century (Armayor 1985). A reconstruction of the Egyptian Labyrinth in the form of a copperplate engraving was included in the book "Description de L'Egypte", which documented the French expedition to Egypt (See Figure 6.9). It shows the Labyrinth as a subterranean structure beneath the Roman town that was believed to have been built on top of it later in history. The underground structure is shown as a massive building with multiple columns and including some Ancient Egyptian architectural features.

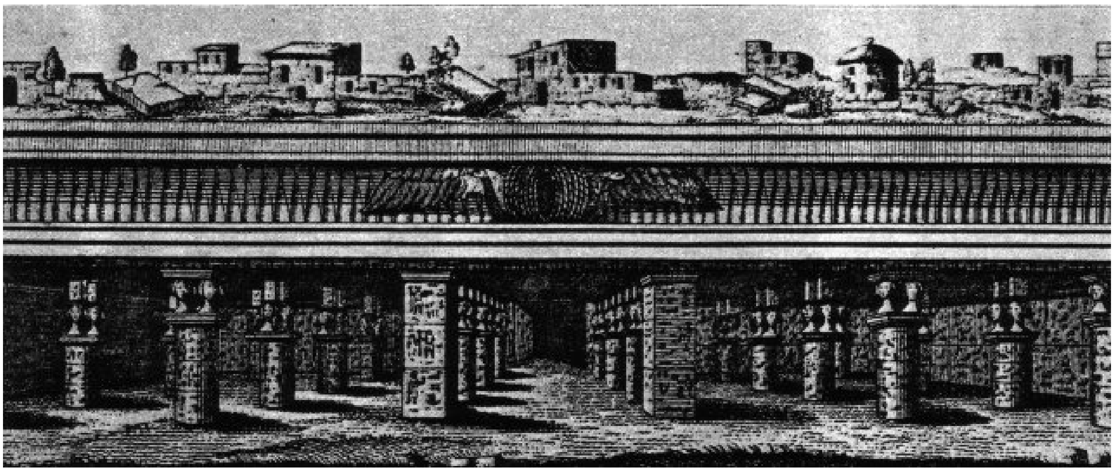


Figure 6.9: Copperplate engraving of the Labyrinth site from “Description de l’Egypte” Paris 1809.

6.5.3.2 The Prussian Expedition 1843 - 1845

Karl Richard Lepsius, a German Egyptologist and a founder of modern, scientific archaeology, did much to catalogue Egyptian remains and establish a chronology for Egyptian history. Following studies in archaeological philology and comparative languages, he became a lecturer at the University of Berlin, and in 1843 he carried out an expedition in the area surrounding the Labyrinth. He unearthed a series of underground brick chambers and claimed to have found the actual site of the Labyrinth; however, it is unclear whether these brick ruins were actually remains of the Roman town which was built on the site (Matthews 1970). Lepsius made a drawing of the ruins at the time of his visit and a map of the site, and these were later published in his book *Monuments from Egypt and Ethiopia*, *1849-1959* (See Figures 6.10 and 6.11).

Figure 610.: Fayoum, view of Labyrinth and pyramid at Hawara, illustration from Monuments from Egypt and Ethiopia, 1849-1959, by Karl Richard Lepsius (1810-1884)

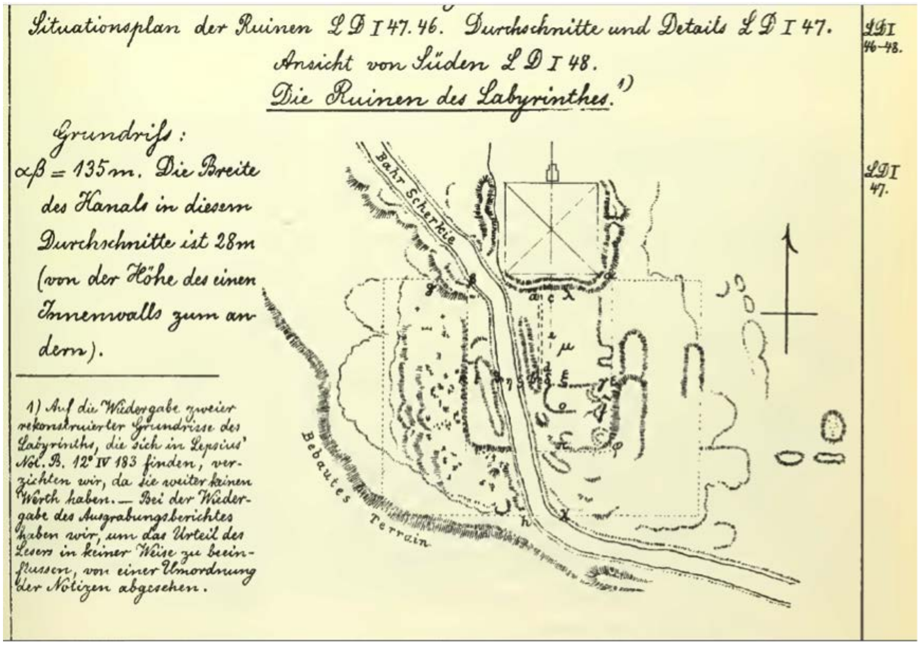


Figure 611.: Map of the Labyrinth site by Karl Lepsius. Source: https://onstellar.com/blogs/65192/The-Great-Maze-in-Egypt-Results-From-a-New-Scanning

6.6 Archaeological Evidence

In addition to the textual and visual evidence available, some archaeological evidence of the site still exists, much of which was collected by the British Egyptologist Sir Flinders Petrie during his excavation at the Hawara Pyramid site in 1888. As a result, the largest collection of antiquities is now at the Petrie Museum of Egyptian Archaeology at University College London, but there are artefacts in numerous museums around the world, notably the Egyptian Museum in Cairo. Examples of artefacts collected from the site in the Petrie Museum are shown in **Error! Reference source not found.**below.

In order to explore all possible archival and archaeological evidence from the Hawara Pyramid site, a number of visits to the British Library, the Petrie Museum, the Hawara Pyramid site, the Egyptian

Figure 612.: Artefacts from the Hawara Pyramid Site now exhibited at the Petrie Museum of Egyptian Archaeology. Source: https://www.ucl.ac.uk/culture/petrie-museum

Museum, and two other sites in Fayoum, namely the Lahun pyramid site and Karanis Town, were made. The main aim in visiting the other archaeological sites in Fayoum was to generate a better understanding of the relationship of the Egyptian Pyramid site to other surrounding sites in order to decide which data to present within the virtual reality experience. The data collected included visual and textual material, and photogrammetry technology for constructing 3D models of the archaeological evidence from Hawara was used. This was done in order to explore the possibility of using AGIsoftware to generate digital copies of the archaeological artefacts for the purposes of integrating them within the virtual reality experience. Table 6 includes the dates and locations of the sites visited by the author as well as the main purpose of each visit.

Table 6: Site Visits

Site Visit	No. of visits	Date of Site Visit	Main Purpose
British Library, London	1	30 October 2018	Flinders Petrie's publications
Petrie Museum, London	1	30 October 2018	Archaeological Evidence
Hawara Pyramid Site, Fayoum	1	7 April 2019	Preliminary Case Study Visit
Egyptian Museum, Cairo	4	7-10 September 2019	Archaeological Evidence and Museum Collection
Hawara Pyramid Site, Fayoum	1	14 September 2019	Case Study Archaeological Evidence
Lahun Pyramid Site, Fayoum	1	14 September 2019	Contextual Research
Karanis Town, Fayoum	1	14 September 2019	Contextual Research

6.6.1 *Archaeological Evidence Discovered by Petrie*

When Petrie visited the site in 1888, there was not much of the Labyrinth itself left. However, he concluded that it was definitely the actual site, located to the east of Lake Moeris, opposite the ancient town of Arisnoe (Crocodilopolis), and just to the south of the pyramid of Hawara. He also deduced that the brick chambers discovered by Lepsius were actually remains of the Roman town constructed by the destroyers of the Labyrinth. Even though the Labyrinth was largely in ruins, some interesting antiquities were found, including parts of the foundations, a great well, two door-jambs - one to the north and one to the south - two granite shrines and parts of another, several fragments of statues, and a large granite seated figure of King Amenemhat III, (now known to be the builder of the Labyrinth).

Figure 6.16 below shows one of the shrines, dedicated to Amenemhat III, which was discovered by Petrie and is now exhibited in Cairo. The remains of the foundations Petrie discovered were sufficient to enable him to predict the size and orientation of the building, and he estimated that the Labyrinth probably covered an area of 1000 feet (from east to west) by 800 feet (from north to south) in the district now known as Fayoum (Matthews 1970).

Petrie provided the following description of the Labyrinth, but he admits that it is highly speculative because the available evidence was insufficient to enable him to predict the real design:

> *"the building was square with additional structures on the east; that it had a great front wall, and a great cross wall along the middle; that the level was uniform, except along the north edge (perhaps outside the building) and at the N.E. outbuildings; that real granite columns were used, but more likely only in the northern part of the site; and built pillars, rather than monolith columns, seem to belong to the part south of the cross wall. This is very meagre information to gain about such a great building, but it is probably about as much as we can ever know; the ground seems to have been exhaustively quarried for stone, and although I turned over a good-sized piece of half an acre or so, examining every chip down to the sand bed, there were only two fragments of inscribed granite as a result. Doubtless some few more fragments might be obtained, but it seems very unlikely that we shall ever recover the plan of the building after the very foundations of it have been removed; especially as it was built upon desert ground, so that there are not even the lines of sand substratum which may be traced in the sites of buildings on Nile soil."* (Petrie 1889, p. 6)

Petrie discovered a huge stone platform during his excavations at Hawara which he assumed to have been the foundation of the Labyrinth. This led him to question the number of courts indicated by Herodotus because the area of the Labyrinth, although massive, might not have been large enough to accommodate the 12 chambers. Petrie compares the text written by Herodotus with other ancient Egyptian sites such as the chambers of Abydos and its hypostyle hall. Through those comparisons he reaches a consensus which enabled him to develop several possible reconstructions for the Labyrinth found in the following figure . His final conclusion was that the number of courts was actually six. He also compared the description of Herodotus with that of Strabo and shows, noting how they contradicted each other in describing the courts. For example, Herodotus described them as being open air spaces all enclosed by one wall while Strabo's description indicated that it was a roofed place.

Petrie justified this on the basis that the front part of the Labyrinth, described by Herodotus as having 12 courts, may have been destroyed by the time Strabo visited the site. Petrie also comments on the written description by Pliny, stating that it included several inconsistent facts that were hard to comprehend and reach a consensus through. According to Pliny, the Labyrinth included 12 *nome* courts with 40 statues of Nemesis "the Greek goddess of retributive justice" as there was no other place for those statues to be placed except on the 40 columns in the front part of the Labyrinth. Petrie concluded from Pliny's description that the courts could accommodate the 12 nomes that were mentioned by Pliny and also that the temples of all the god and goddesses might well be accommodated within the premises of the building (Petrie 1889). Petrie also compared the text written by Herodotus with other ancient Egyptian sites, such as the chambers of Abydos and its hypostyle hall.

Through comparisons with the texts of Herodotus, Strabo, and Pliny, and his own excavations on site, Petrie reached a consensus which enabled him to develop several possible reconstructions for the Labyrinth based on. The following figures are virtual reconstructions for the Hawara Pyramid and Labyrinth site created by Petrie and now held by The British Library (See Figures 13-15).

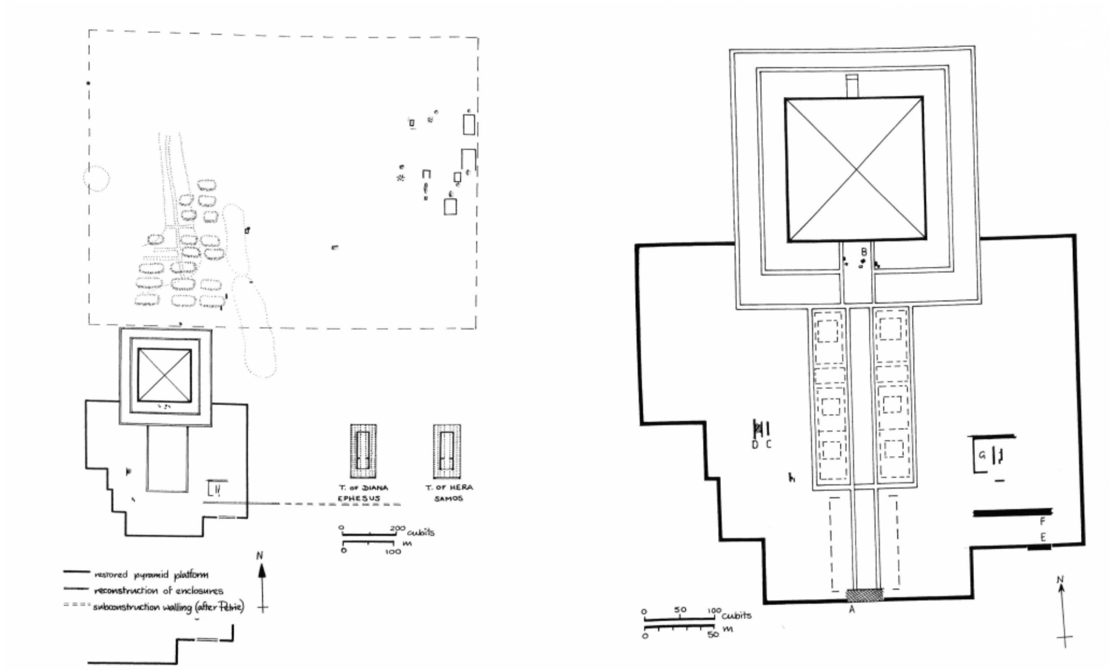


Figure 613.: Petrie's Reconstruction of the Labyrinth, showing a proposed layout overlayed on the restored pyramid platform. Source: British Library Collection

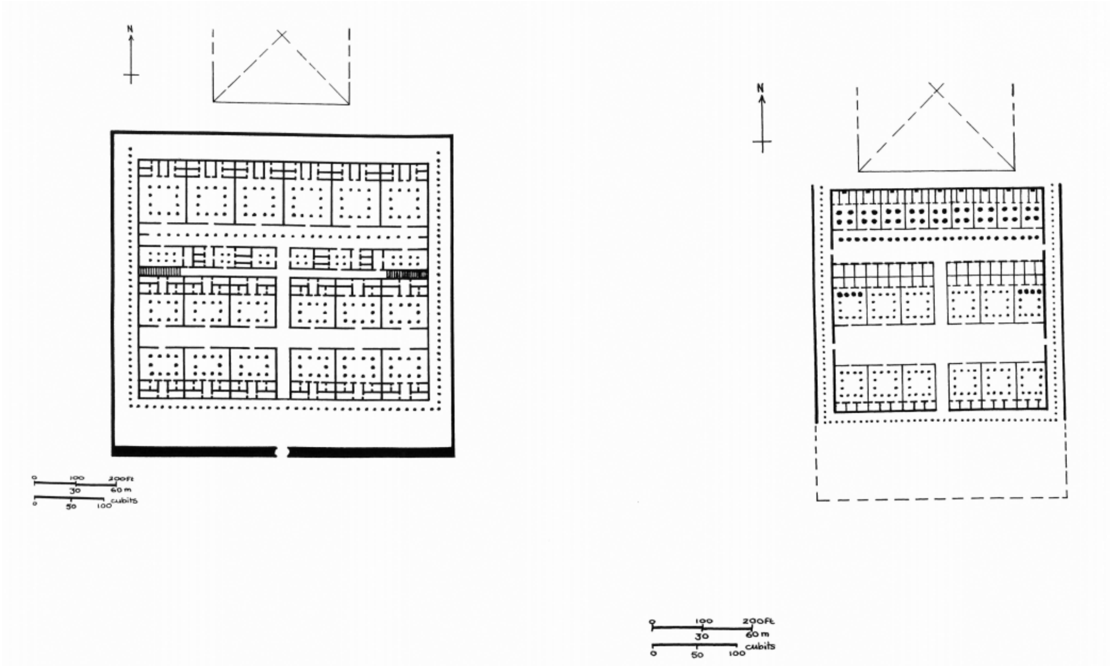


Figure 6.14: Architectural plans showing Petrie's Reconstruction of the Labyrinth, British Library Collection

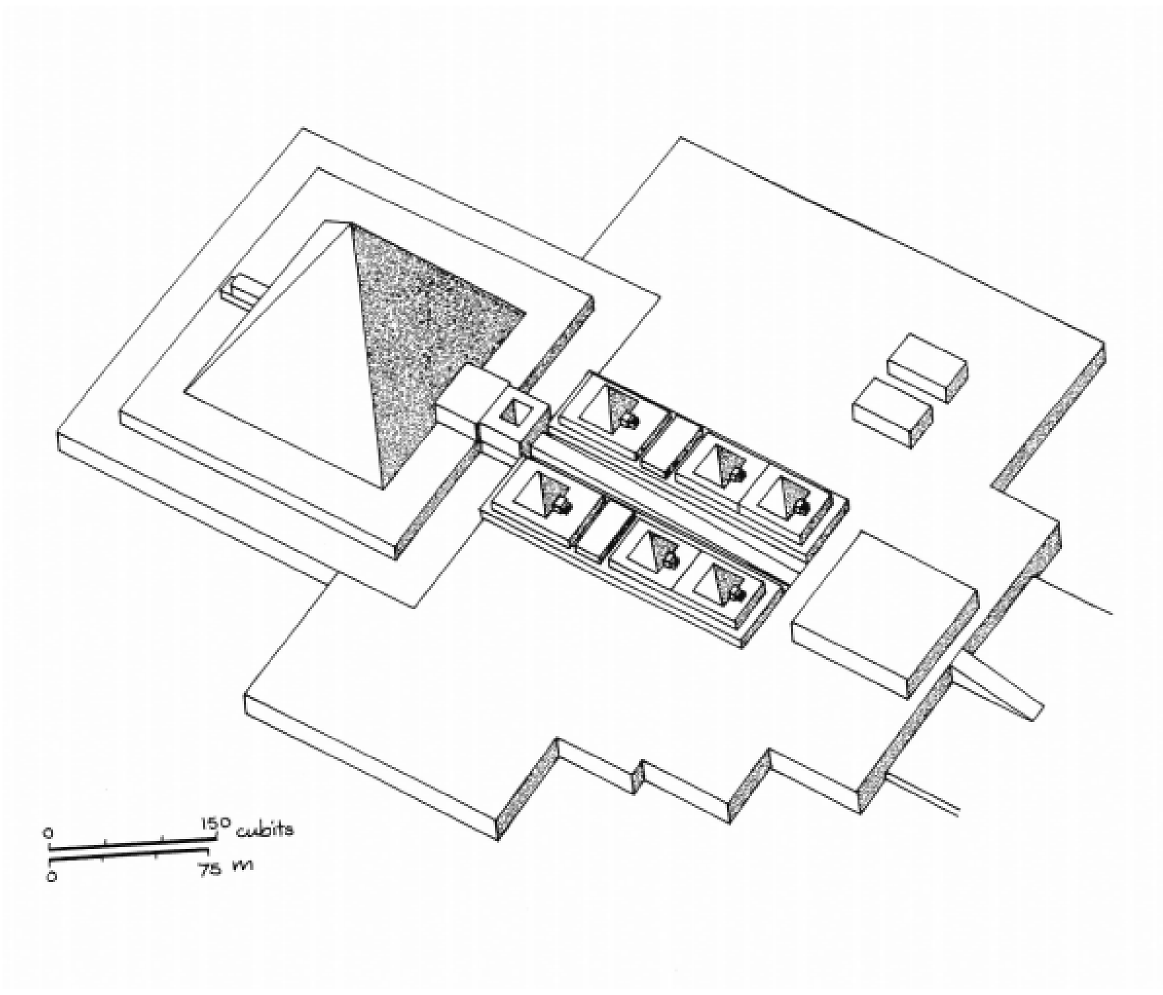


Figure 6.15: Axonometry showing Petrie's reconstruction of the Egyptian Labyrinth, British Library Collection

6.6.2 *Archaeological Evidence at Egyptian Museums*

The largest collection of artefacts from the site of the Labyrinth in Egypt is located in the Egyptian Museum in downtown Cairo at the time of writing, although some of the pieces are scheduled to be transferred to the new Egyptian Museum. The database at the museum was reviewed during the visit in September 2019 to select important pieces that would be useful for building the architectural models for the virtual reality experience.

The most important piece at the museum is the Shrine of Amenemhat III (Granite Naos), which was excavated by Petrie, and now stands in the courtyard of the Egyptian Museum in Cairo. The images in Figure 16 show the shrine both when it was excavated and as it appears now at the museum.

Figure 6.16: Egyptian Labyrinth Shrine of Amenemhat III discovered at Hawara by Petrie now exhibited at Cairo Museum.
Source: https://commons.wikimedia.org/wiki/File:Amenemhat_III_-_IV.jpg

The Shrine of Amnemhat III was documented using multiple photos and converted using Agi Soft software into a three dimensional model using photogrammetry. The following images are screenshots of the final model (See Figure 6.17).

Figure 6.17: 3D Photogrammetry Model of Amenemhat III Shrine excavated by Petrie currently located at the Egyptian Museum, Cairo. Source: Created by the Author

Other museums in Egypt also contain archaeological evidence from Hawara; however, due to the lack of online databases for all museums it was difficult to cover all the archaeological evidence relating to the site. Nonetheless, as part of the field work research study, Kom Ushim Museum was visited as it is the only museum located in the city of Fayoum. There were only two pieces from Hawara at this museum and they are both architectural fragments made of limestone. A 3D model was generated for one of these using the same method as for the shrine (See Figure 6.18).

Figure 6.18: View 1 3D Photogrammetry model of a limestone architectural fragment from the Hawara Pyramid site, currently located at Kom Ushim Museum. Source: Created by the Author.

Figure 619.: View 2 3D Photogrammetry model of a limestone architectural fragment from the Hawara Pyramid site, currently located at Kom Ushim Museum. Source: Created by the Author.

6.6.3 *Archaeological Evidence at the Hawara Pyramid Complex*

Some of the remains and architectural fragments are still left at the site of the Labyrinth at the Hawara pyramid complex. The fragments are either remains of the lost Labyrinth, parts of the previous cladding of the pyramid (limestone), or mud brick remains from the Graeco-Roman village. These fragments are considered an important resource in attempting to reconstruct different models of the Labyrinth through history, so images of some pieces were captured on site in order to generate 3D photogrammetry models using Agi Soft software. The following images are examples of the models created from these fragments (See Figures 6.20 and 6.21).

Figure 6.20: 3D Photogrammetry model of a column fragment from Hawara Pyramid Site
Source: Created by the Author

Figure 6.21: 3D photogrammetry model of a column cap fragment from Hawara pyramid site
Source: Created by the Author

6.6.3.1 Research Work on the Archaeological Remains at the Hawara Pyramid Site

While the textual and visual evidence given above provides historic descriptions of the Egyptian Labyrinth and its remains, the work of contemporary researchers is also important. For example, the architectural fragments relating to the Labyrinth were thoroughly studied by Eric P Uphill in his book "Pharoah's Gateway to Eternity: the Hawara Labyrinth of King Amenemhat III" (Uphill 2000). The book compares the viewpoints of different scholars about the Egyptian Labyrinth using textual and archaeological evidence that exists today, both on the site itself and in the museums. It includes key numerical information and measurements of the archaeological remains which were used as a reference in the virtual reconstruction; however, the author does not address any previous reconstructions. The book also includes a brief study of the Twelfth Dynasty pyramid complexes, but it focuses on the Labyrinth site during the Middle Kingdom period.

An important reference in relation to the Hawara pyramid site during the Graeco-Roman period is "Hawara in the Graeco-Roman period; Life and Death in a Fayum Village" by Uytterhoeven and Marchand (Uytterhoeven & Marchand 2009). The book covers a period of almost 3000 years, reaching from the 12th Dynasty (ca. 1800 BC) to the Arab Period (10th century AD). Taking the sources related to the Graeco-Roman occupation of Hawara as a starting point, this monograph offers a picture of life and death in a Fayoum village. The part dealing with the living focuses on the topographical situation of the village, its population, administration, economy and religious life, while the second part focuses on the dead who were buried on the site, reconstructing their socio-economic position and provenance. The book also includes a detailed survey of all the remains of the Graeco-Roman town now found on the site. These plans were used as a base for reconstructing the Graeco-Roman houses of the Hawara village in the virtual reality experience, and an example is shown below (See Figure 6.22).

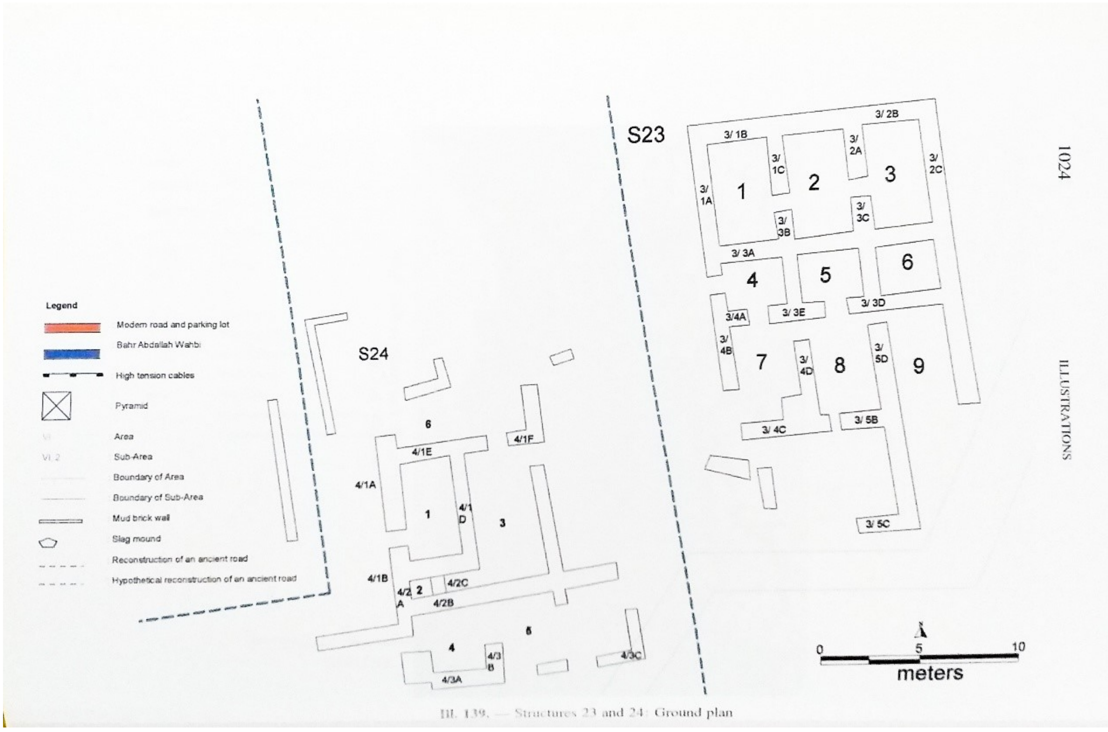


Figure 622.: A sample from the survey of the Graeco-Roman town remains by Uytterhoeven. Source: Uytterhoeven & Marchand 2009 p. 1024

6.7 Contemporary Reconstructions of the Egyptian Labyrinth

The most recent research work on the Egyptian Labyrinth has included reconstruction attempts based on the visualizations that were explored in the previous sections, and it was important to explore these in order to establish the state of the art regarding the case study. The most recent work examined was that by Narushige Shiode and Wolfram Grajetzki of University College London, who explored the possibility of developing a reconstructive model of the Hawara Labyrinth complex using virtual reality technologies. Their reconstruction work was based on literature about the site, such as the description by Herodotus, as well as excavations at the site, and they produced two different 3D models showing possible forms for the Labyrinth, as shown in Figure 22 below (Shiode and Grajetzki 2019).

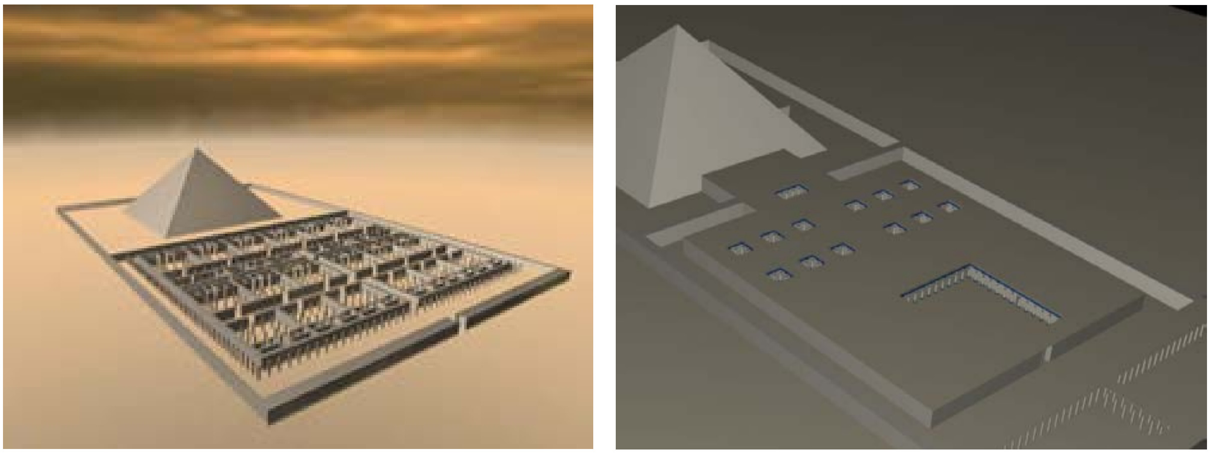


Figure 623.: Reconstruction of the Egyptian Labyrinth showing two possible layouts.
Source: Shiode and Grajetzki (2019)

A slightly earlier work that included a virtual reconstruction of the Labyrinth is that by Louis de Cordier and the Mataha Belgium expedition in 2008. Their reconstruction is clearly based on the plan by Canina (See Figure 67.), as can be seen in the layout below (See Figure 6.23). The project team conducted a historical analysis that included a study for previous reconstructions as well as some geological studies on site (NRIAG – Ghent University/Kunst-Zicht 2008).

6.8 Mapping the Uncertainty in the Textual, Visual and Archaeological Evidence

Through studying the different types of available evidence related to the Egyptian Labyrinth of Hawara, it is clear that there is a high degree of subjectivity involved in the textual, visual and virtual reconstruction attempts generated over time. Figure 26 provides a history of the exploration of the Hawara site and shows the evidence produced, both actual physical evidence and drawings by travellers who visited the site. It also shows the visualizations created through history, recognising those which did not have enough reliable sources and which, in some cases, were entirely the work of the author's, historian's or artist's imagination. There are also cases, such as in the book "Description de l'Egypte" and in the books written by Petrie, where part of the evidence provided was factual and another fictional. This is also clearly demonstrated in the Figure 6.24.

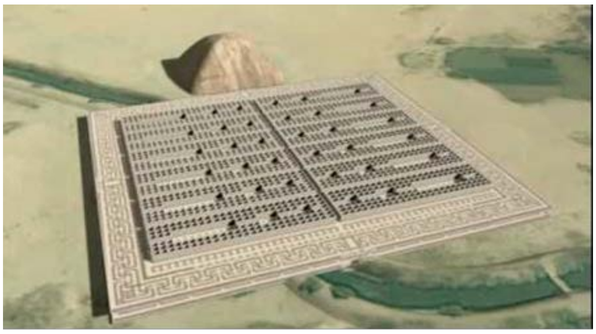


Figure 624.: Reconstruction of the Egyptian Labyrinth by the Mataha Expedition
Source: Mataha Expedition 2008
https://issuu.com/yago1/docs/labyrinth_of_egypt_com__hawra_2015

6.9 Conclusion

The study of the Egyptian Labyrinth in-between virtuality and reality makes it clear that the reconstruction of archaeological sites, especially those sites with minimal physical remains on site, have the potential to misinform the public. It is also evident that, throughout history, starting with Greek authors, moving on to Renaissance artists and later expeditions and explorers, up to contemporary archaeologists using current academic approaches and the latest technologies, there exists a high degree of speculation that was not always made clear to the researchers or the public who saw these visualizations. The last section of the chapter includes a photogrammetry study of actual remains that were collected from the site to show the difference between the actual remains and the reconstruction attempts that were not based on archaeological evidence. These reconstructions were actually mostly based on narrations that developed over time from one expert to another.

As discussed in previous chapters, the visual communication of history is quite influential in shaping the public's perception of history, and it can contribute greatly to public understanding of certain archaeological sites that no longer exists. This highlights the importance of providing clarity to the public when presenting visualizations, whilst avoiding the risk of seeming overbearing or hard to comprehend. It should be made clear that there are multiple realities for those archaeological sites, and that there was a degree of uncertainty and subjectivity within the reconstruction process. Virtual reality provides the capacity to present multiple models within the same virtual reality experience, and it also allows for the integration of multimedia, which could be informative for the public in an accessible way. The next chapter explores the effectiveness of virtual reality as a medium to convey the uncertainty and subjectivity within the reconstruction process by creating a virtual reconstruction of the Egyptian Labyrinth using the evidence collected in this chapter, comprising three different models presenting. The virtual reality experience will allow users to navigate through the three models and interact with multimedia elements that gives information about them and how they were created. This approach is a novel approach as it includes the facility to navigate between several models within one simple interactive experience.

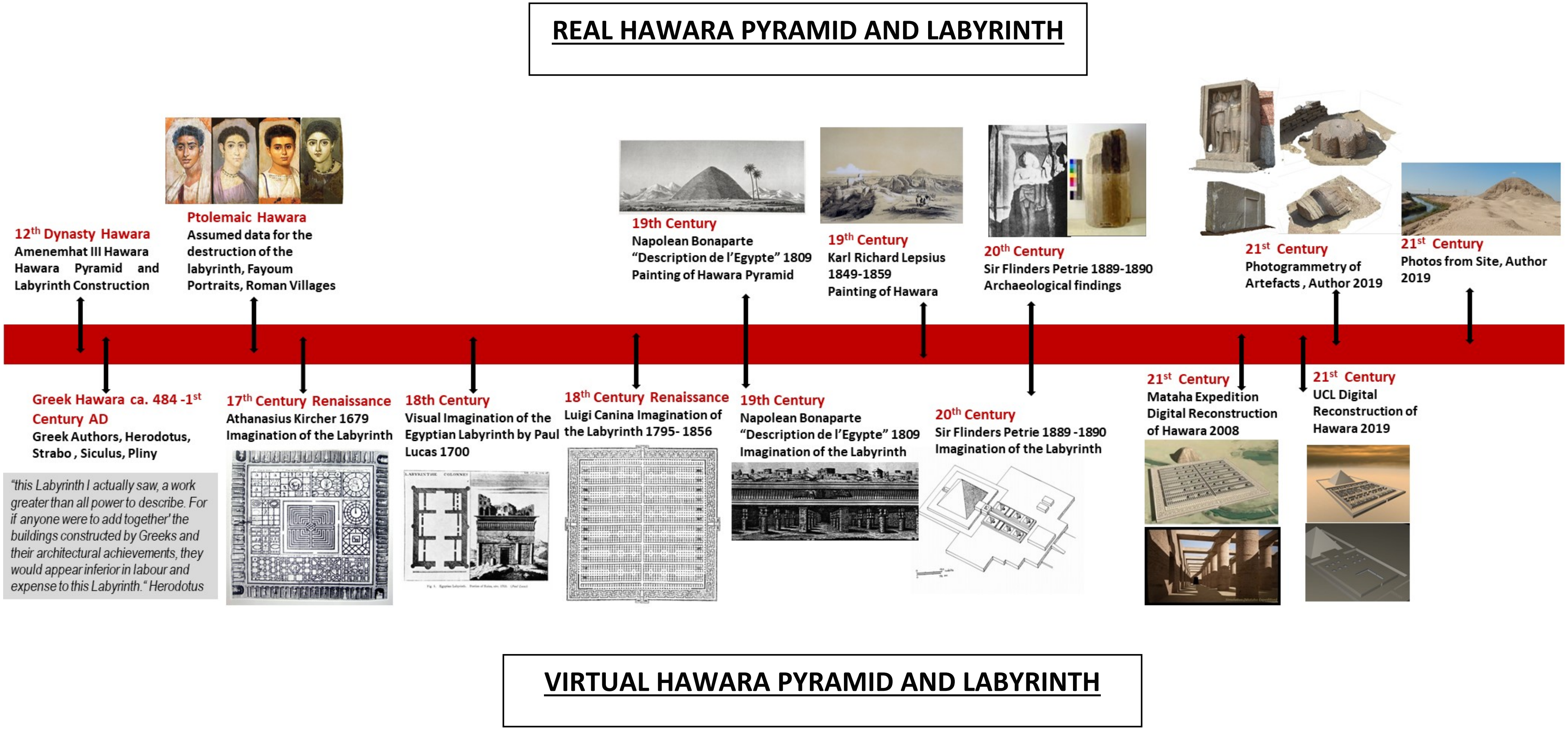


Figure 625.: History of the Hawara Pyramid and Labyrinth in between the real and the virtual

7. CHAPTER 7: VIRTUALIZING THE UNCERTAINTY OF DIGITAL ARCHAEOLOGICAL RECONSTRUCTION

7.1 Introduction

This chapter provides a description of the development of a virtual reality experience based on the Egyptian Labyrinth site in Fayoum, Egypt, which was created with the aim of presenting the uncertainty inherent in digital archaeological reconstructions. As explained in Chapter 5, in order to identify the most appropriate approach for generating a virtual reality experience, the first step is to identify the aim of the project. This virtual reality experience aims to present the uncertainty of digital archaeological reconstructions to a general audience and to act as a prototype for an experience which could be used in a museum setting or an archaeological site. As such, it was important to identify the most appropriate approach, tools, and methods to achieve this, and these are discussed below. However, the main factors that determined the approach selected, namely presenting several interpretations of the Labyrinth by different historians, travellers and artists, were the researcher's technical skills and the availability of the software.

The following diagram (See Figure 7.1) shows the process of developing the virtual reality experience, beginning by identifying the project aims (representation and dissemination), the target users (the general public), and determining the available resources (time, funds, and the researcher's technical knowledge). Given the nature of doctoral research, the available budget was quite small, and the time frame was limited to one year, which ran in parallel with other research work, such as data gathering and interviews. These restrictions limited both the amount of detail provided in the virtual reality experience and the number of scenes presented. For example, only a single virtual reality experience was generated and tested, not several proposals as suggested in Chapter 5. The next step was to identify which types of evidence could be used in the generation of the virtual reality experience. Not all the potential sources of evidence could be used, as only three different reconstructions are presented, those by Kircher, Lucas, and Canina. This choice was made firstly as this experience is just a demo, secondly due to the complexity of adding further models within the same virtual reality experience, and, thirdly, due to the limitations of time and resources.

These constraints and the nature of the research (a doctoral thesis) meant the model did not undergo a peer review process. However, as this is a demo which is intended to show how uncertainty can be conveyed, that is not a significant obstacle at this stage. User feedback on the effectiveness of the experience was gathered, however, and this is described in the next chapter.

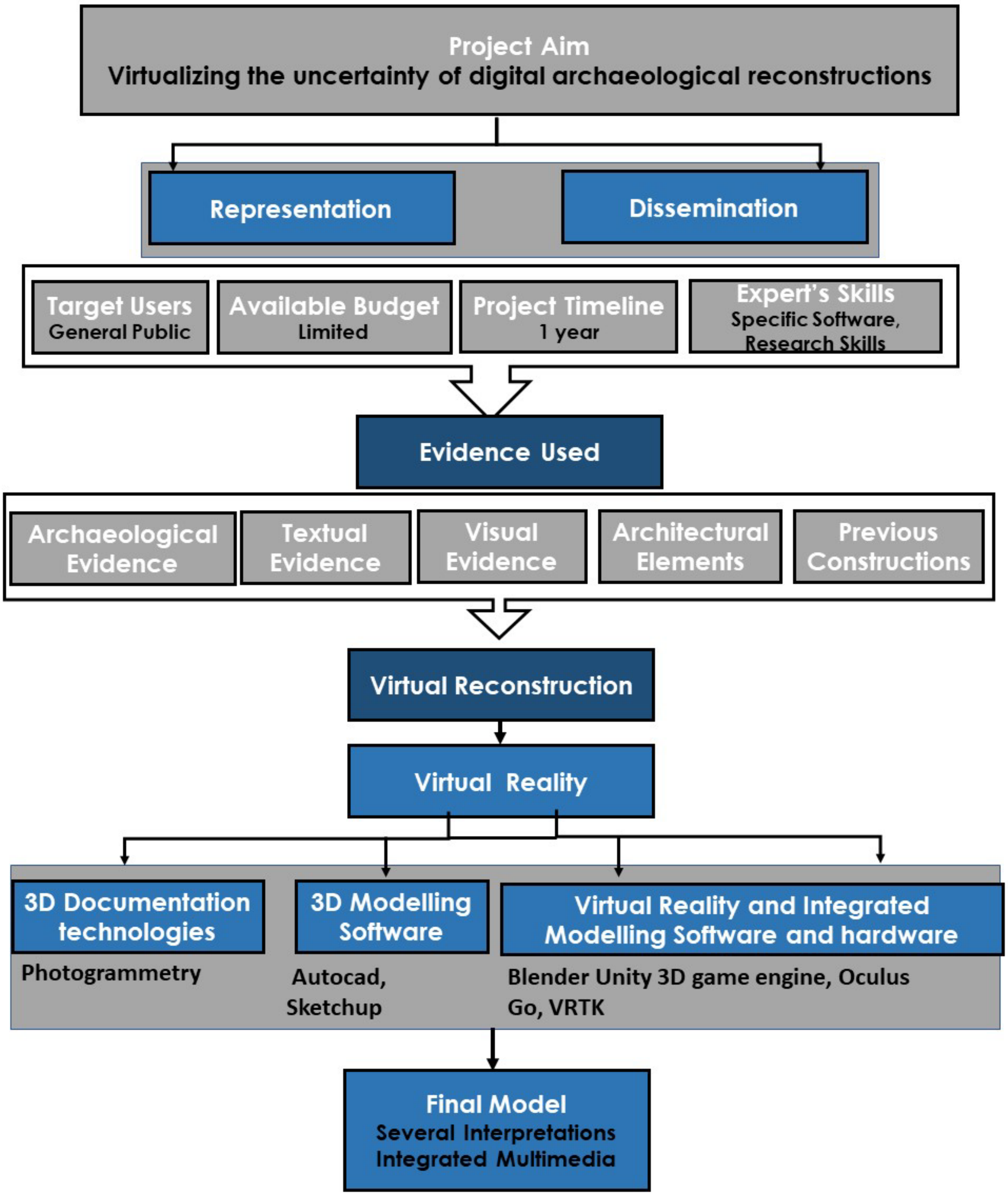


Figure 7.1: Framework for virtualizing the uncertainty of the digital archaeological reconstruction of the Egyptian Labyrinth at Hawara.
Source: Created by the Author

7.2 Digitization of the Historic Two-Dimensional Drawings

The first step in creating the virtual reality experience involved converting the 2D drawings created by Athanasius Kircher, Luigi Canina and Paul Lucas into digital drawings for the first phase of the 3D modelling.

The drawing by Kircher (1679) provides a plan of the Labyrinth, with parts of the elevation of the arcade drawn on the edges, a technique Kircher used throughout his book to combine plans with elevations (Kircher, 1679). The layout by Kircher represents the Labyrinth as a maze with courts surrounding it and each of them has a different shape. The layout was digitized using Autocad software and then used to create a layout for the walls in the first phase of the three-dimensional modelling (See Figure 7.2). The elevations and internal details of the statues found in Kircher's original drawing were added in later phases of the 3D modelling.

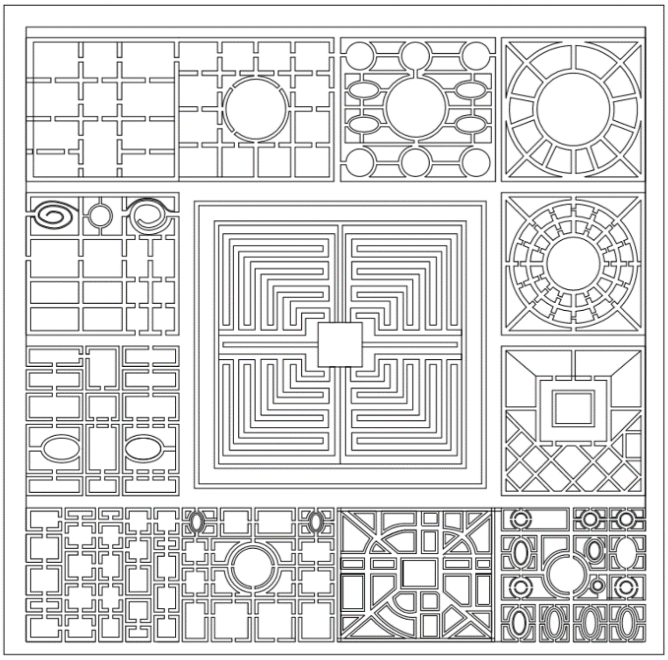


Figure 7.2: 2D digitization of the reconstruction of the Egyptian Labyrinth by Athanasius Kircher. Source: Created by the Author using Autocad software

The drawing by Paul Lucas (1700) include a proposed plan for part of the Labyrinth and an elevation. These were both converted into two dimensional digital drawings using Autocad software (See Figure 7.3). The elevation includes some ancient Egyptian features that were used in other historic buildings; however, the overall layout and design does not match the designs known to be typical of Ancient Egyptian temples (Fletcher and Cruickshank, 1996). As a result, the 3D visualization only reflects the proposed plan by Paul Lucas, staying as close as possible to the two dimensional drawings, with images and text integrated to provide some information about Paul Lucas.

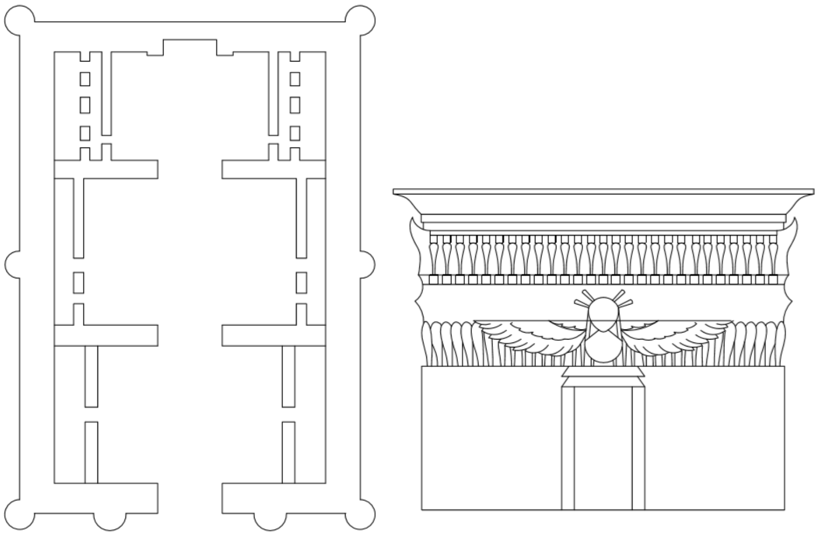


Figure 7.3: 2D digitization of the reconstruction of the Egyptian Labyrinth by Paul Lucas.
Source: Created by the Author using Autocad software.

The drawing by Canina provides an overall plan of the layout of the Egyptian Labyrinth, which was converted into a 2D digital drawing in Autocad (See Figure 7.3). As no indication of how the elevations might have looked is provided, reference was made to architectural features known to be typical of the period in order to create the 3D visualization. Thus, the type of columns used in the 3D model were chosen to replicate the most commonly used columns in ancient Egyptian temples (Fletcher and Cruickshank, 1996). This is hypothetical to some degree; however, the model includes a panel that shows the original visualization by Canina in order to be as clear as possible to the user. This plan by Canina was used as a base for the 3D modelling, as explained in the following section.

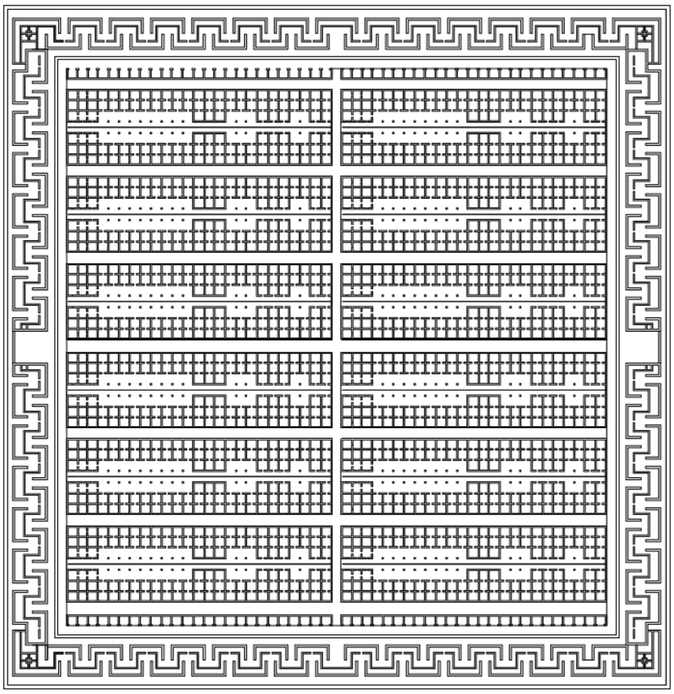


Figure 7.4: 2D digitization of the reconstruction of the Egyptian Labyrinth by Luigi Canina. Source: Created by the Author using Autocad software.

7.3 Three Dimensional Modelling

The second phase included converting the 2D digital plans and elevations into 3D models using Sketchup 2020 software. The initial models were created by simply adding the third dimension to the 2D models. The two reconstructions created by Kircher and Canina were presented in relation to the Pyramid, as they provide a full reconstruction of the whole Labyrinth. However, as the reconstruction by Lucas presents only a portion of the ruins, the 3D model was created as a detailed representation of how a section of the Labyrinth might have looked like, with no connection to the Pyramid. The heights of the 3D models of the reconstructions provided by Kircher and Lucas were determined based on their drawings in relation to the portion of the elevation they provided. Figure 7.5 shows the initial model of Kircher's visualisation presented in relation to the Pyramid, created by combing the Autocad drawing with the visual imagination inside the Sketchup file.

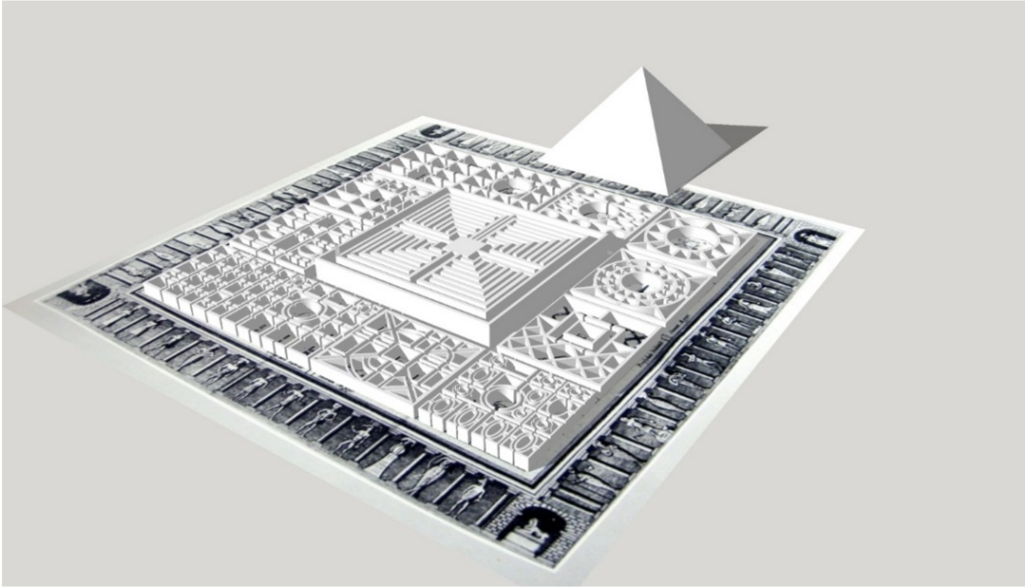


Figure 7.5: Initial 3D model of Kircher's reconstruction.
Source: Created by the Author using Sketchup software

Figure 7.6 shows the 3D visualization of Lucas's imaginative recreation of the Labyrinth. The 3D model is a combination generated from the drawings of the plan and elevation, with no additions made to the model. The amount of detail in the original drawing of the elevation was enough to give a certain degree of realism that could be presented to the users.

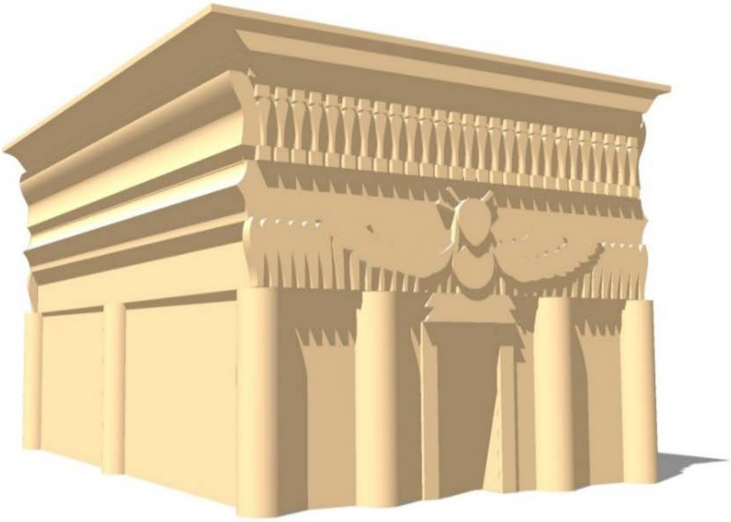


Figure 7.6: Initial 3D model of Paul Lucas's reconstruction.
Source: Created by the Author using Sketchup software

Figure 7.7. demonstrates the 3D reconstruction based on Canina's reconstruction. In its initial stage, the 3D model only included the main layout converted into three dimensions. However, it was evident at this stage that the models needed some additions, including architectural features as well as textures and materials, to create a certain degree of photorealism. This would make the models more suitable for use with the general public. The process involved in adding textures and architectural elements is explained in the next section.

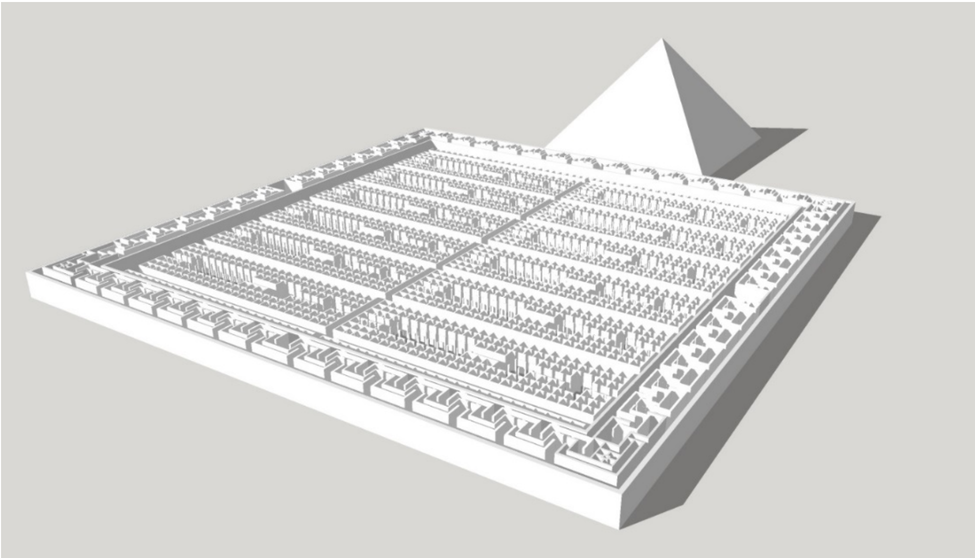


Figure 7.7: Initial 3D model of Canina's reconstruction.
Source: Created by the Author using Sketchup software

7.4 Adding Textures to the Three-Dimensional Models

The next phase involved adding further details to the three-dimensional models in order to give them a photorealistic quality within the virtual reality experience. In order to be able to achieve this, details such as statues and columns were added to recreate, as closely as possible, the elevation drawings done by the historians. As mentioned above, some details, such as the column capitals for the model by Canina, were assumed based on archaeological remains on site and other similar buildings. The textures used were selected simply to make the building as close as possible to other examples of Ancient Egyptian architecture. As the reconstructions are all hypothetical, dependence on archaeological findings was not the main source of evidence. The focus within this virtual reality experience is to provide enough evidence for users to understand that the 3D models they are exploring are reconstructions based on the imaged images created by certain historians. Therefore, although the virtual reality experience was created in line with the theoretical recommendations set out in the literature review chapter as well as the London Charter (2009) and

Seville Principles (2011) as far as possible, it was acceptable, in this case, to add some elements to complete the three-dimensional reconstruction in order to make them more visually appealing.

The following screenshots from the virtual reality experience demonstrate the results of adding elements to the 3D visualisations of the Labyrinth. The first screenshot (See Figure 7.8) demonstrates the textures, columns and statues added to the 3D modelling of the reconstruction by Kircher. The chosen columns are similar to Greek Doric columns,[4] as they were the closest type to those drawn by Kircher. This is not an Ancient Egyptian column; however, the aim was to use elements that are as close as possible to the original visualization. As for the statues, a number of models of Ancient Egyptian gods and goddesses were positioned to resemble Kircher's elevation. The textures used for the walls were taken from samples of Ancient Egyptian temples in order to indicate the time period during which the reconstruction was done which is the 11th dynasty of ancient egypt and resembles Kircher's imagination of it. The textures are not designed to be highly photorealistic as the aim is to convey that the models are based on imagination rather than archaeological evidence from the site. This approach was also adopted due to the limitations of the equipment available and the restricted time frame to create the virtual reality experience.

Figure 7.8: Screenshot showing the textures used in the 3D model based on the reconstruction by Athanasius Kircher. Source: Created by the Author using Sketchup software

[4] Doric columns are the main type of column order known to be used in ancient Greece. There is no historic record at Hawara to show that the labyrinth was built, or even modified after its initial construction by Amenmhat III, by the Greeks. This indicates that this type of column could never have been used in this site at any historic period.

The following screenshot shows a detail from the 3D model based on the reconstruction by Lucas. No architectural elements were added to the original two-dimensional drawings, but a single texture including ancient Egyptian engravings was applied (See Figure 7.9). This was used in order to show this part of the Labyrinth as a more realistic building, which is more suitable for the virtual reality experience. No more details were added as the capacity of real-time rendering in virtual reality experiences is limited. This was important to take into consideration while creating the models.

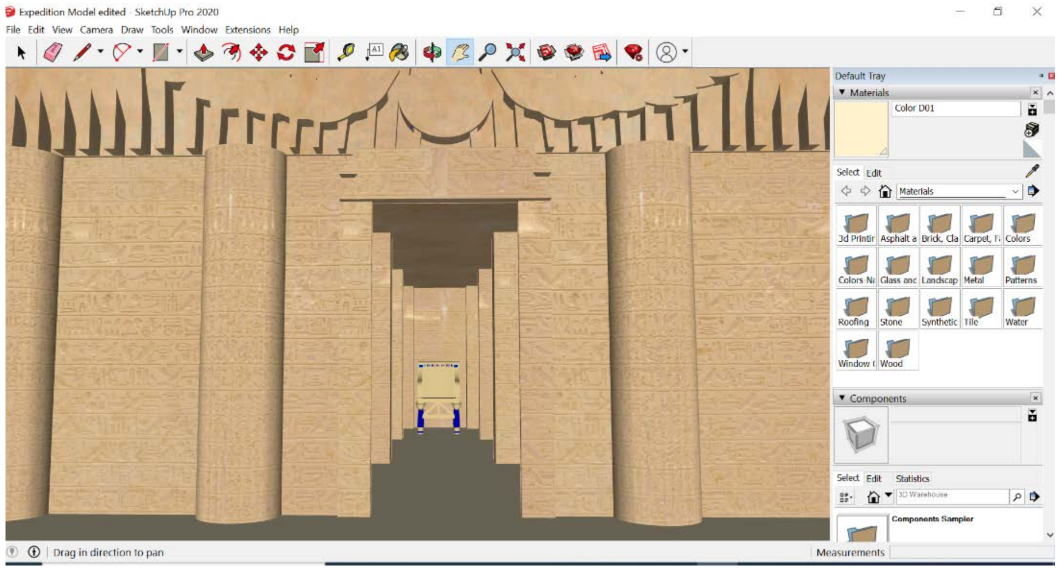


Figure 7.9: Screenshot showing the textures used in the 3D model based on the reconstruction by Paul Lucas. Source: Created by the Author using Sketchup software

The following screenshot shows the textures, Ancient Egyptian lotus closed bud[5] columns and pylons[6] that were used to add a third dimension to the reconstruction by Canina (See Figure .10) As previously mentioned, the two-dimensional layout did not give any indication of how Canina imagined the architectural features, the third dimension, or the textures and materials. This is why the most commonly known Ancient Egyptian architectural elements were used. This was done in addition to taking into consideration the only archaeological findings that proved to be beneficial in reconstructing the Labyrinth, which were the column fragments shown in the previous chapter.

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[5] The lotus bud column capital is one of the most common used types of columns in Ancient Egyptian temples. A fragment of this type of column was found among the archaeological findings at Hawara.

[6] Ancient Egyptian pylons were massive, monumental stone structures that were situated at the entrances to the temples. They were characterized by having a lintel in the middle and by being tappered on the sides, giving them a pyramidal shape.

Figure 7.10: Screenshot showing the textures used in the 3D model of the reconstruction by Canina. Source: Created by the Author using Sketchup software

7.5 Virtual Reality Experience Scenario

The following phase involved designing the virtual reality experience scenario. This included creating the design of the virtual reality experience, including the type of interaction involved as well as the types of multimedia that would be integrated into the virtual reality experience. The main aim of using interaction is to enable the user to navigate through the three different models while adding images and voice-overs to provide key contextual data. This included explaining whose reconstruction was being presented and giving information about how they had visualized the Labyrinth. The three models are explored through the user teleporting to different sections of the models.

The following section includes the scenario for the virtual reality experience, explaining each of the four scenes and presenting the voice-over text used to describe each of the expert visualisations.

- Scene 1: The Introduction (Gallery Scene)

The first scene includes a gallery space in a museum with the three models on display. The museum space also includes a panel with images and a 'play' button which enables the user to access a number of different images. The first set of images includes some images from site, and the next set includes the visualizations of the Labyrinth created by different historians. The user is able to move around the museum space and to move through the images. In order to get a closer look at the models, the user can click on each of the model in order to enter inside. The following screenshot (See Figure 7.11) shows the museum space scene with the models at the back and the panel in the front. The next sections include the images and voice-overs used in Scene 1.

Figure 7.11: Screenshot from Scene 1 of the virtual reality experience.

Voice-over 1

"*The Egyptian Labyrinth is one of the wonders of Ancient Egypt. This is why many Greek authors wrote about it in their narratives of Egypt. Herodotus wrote about a great Egyptian Labyrinth located on a great Egyptian Lake, close to a city named after the crocodiles, which is now the city of Fayoum. Other historians such as Strabo, Diodorus , Pliny and Manetho, mentioned the Labyrinth in their writings.*

Hawara in Fayum, known to be the location for the Egyptian Labyrinth, now only includes the remains of the mud brick pyramid of Amenemhat the Third."

Figure 7.12: Images from the site of the Hawara Pyramid and Labyrinth displayed on the panel in Scene 1. Source: Taken by the Author

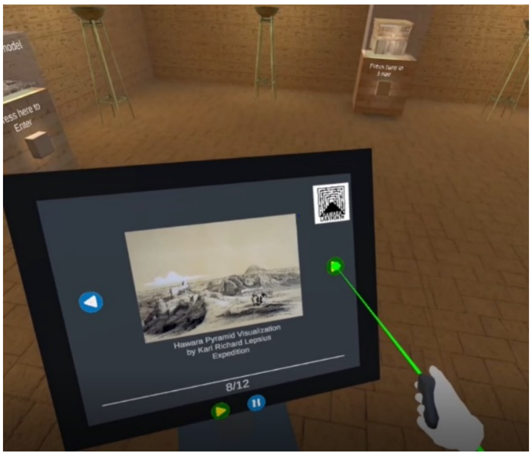


Figure 7.13: Screenshot from the virtual reality experience showing the panel displaying the images of the visualizations by different historians

Voice-over 2

"Other Historians imagined the Labyrinth and created visual descriptions of it".

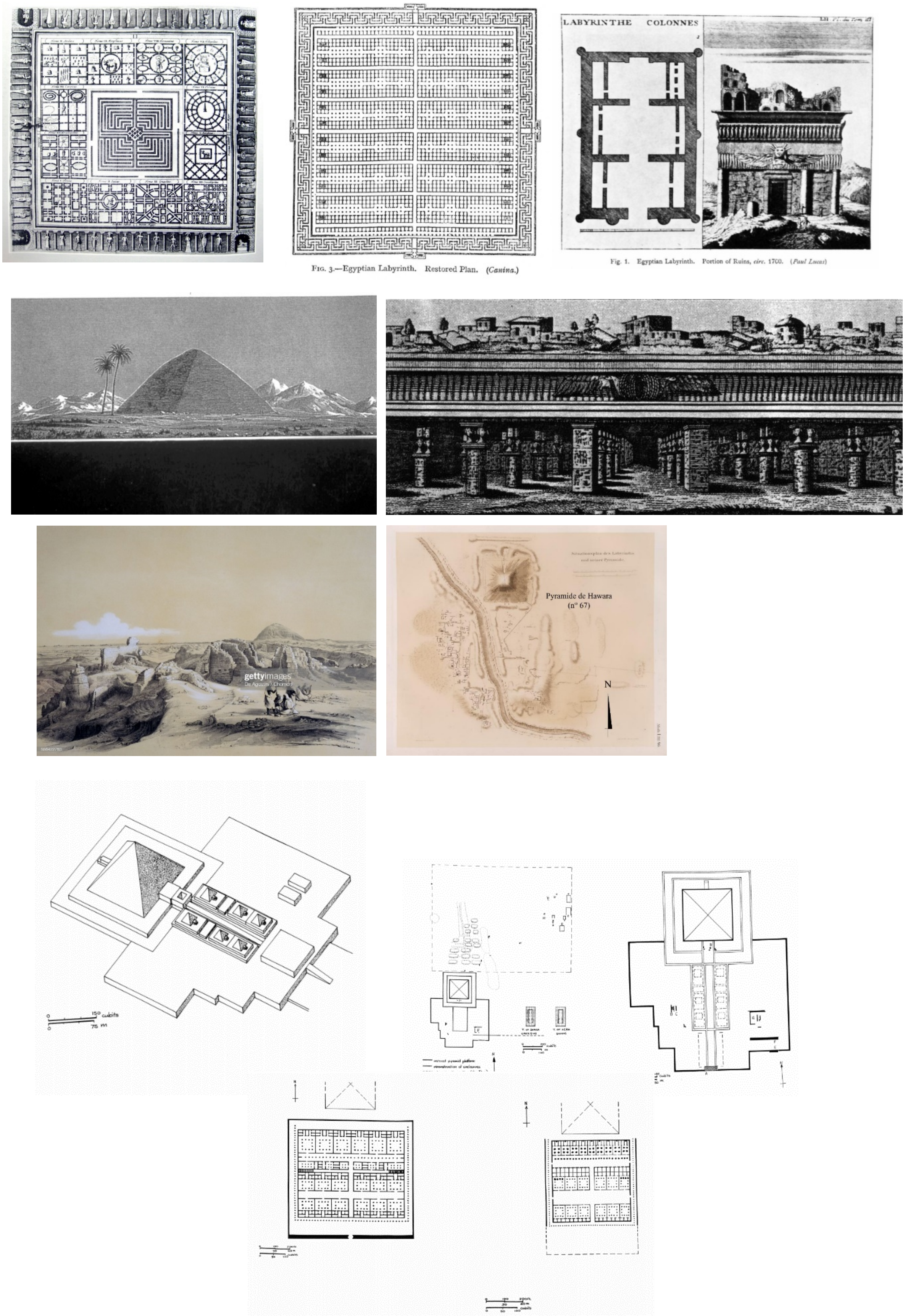


Figure 7.14: Images showing the visualizations of the Labyrinth by different historians displayed on the panel in Scene 1.

- Scene 2: Model 1 (Kircher's visualization)

In order to teleport to Scene 2, the user clicks on the model in the museum scene (as shown in Figure 7.16). The second scene includes the 3D model by Athanasius Kircher, with a panel displaying an image of the original drawing. The user can move to different points around the model in order to view it from different angles (See Figure 7.15). The following sections include the different views available and the voice-overs that are played at each viewing point.

Figure 7.16: Screenshot from Museum Scene showing the teleportation to Scene 2

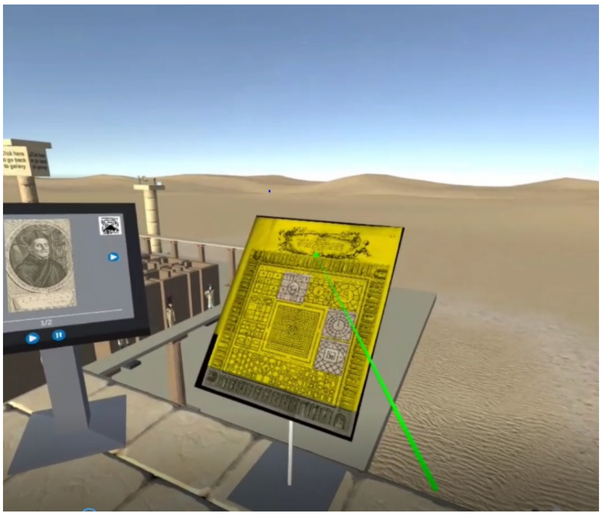


Figure 7.15: Screenshot from Scene 2 showing teleportation to different parts of the reconstruction by Kircher

Voice-over 3

"*Athanasius Kircher was a German Jesuit priest and scholar. He was the first scholar to provide a visual reconstruction of the Labyrinth. The visualization created by Kircher was included in his book "Turris Babel", which was first published in the year 1679*."

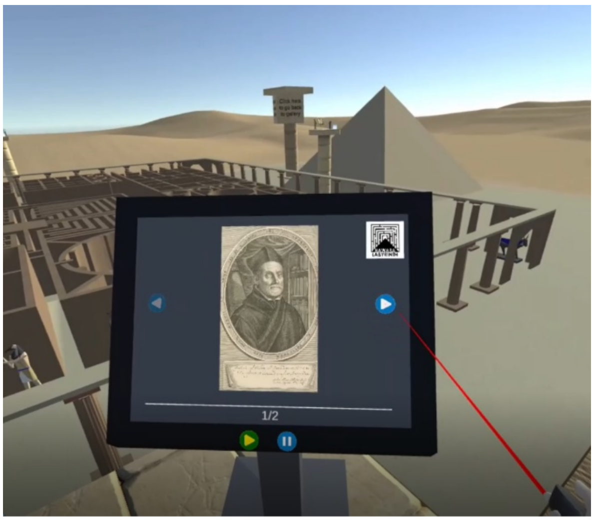


Figure 7.17: Screenshot from virtual reality experience showing a panel with a drawing of Athanasius Kircher.

Figure 7.18: Drawing of Athanasius Kircher. Source:https://commons.wikimedia.org/wiki/File:Athanasius_Kircher_Portrait.jpg

Voice-over 4

"*Kircher's visualization represented the Labyrinth as a square shaped structure with a maze in the middle. The maze is surrounded by 12 courts that he referred to as "Nomes". A nome is known as the territorial division in ancient Egypt, so, in his reconstruction, each court represented a Nome*."

- *Model 1 - Part 1*

From this point, the user can move into the first part of the model, the arcade that includes the columns and capitals (See *Figure 7.19*). There are two panels placed in this scene; one is used for the teleportation to other parts of the model, the other provides more information about this part of the Labyrinth, including Voice-over 5 below.

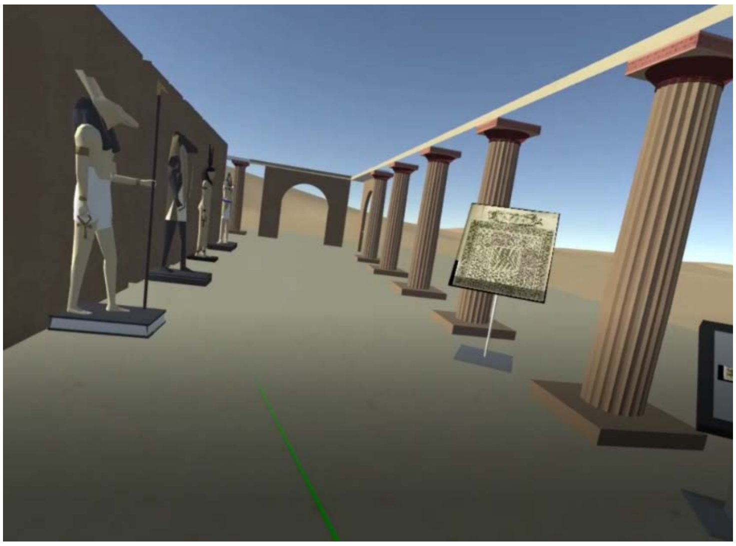


Figure 7.19: Screenshot from the arcade part of the model

Voice-over 5

"*The 12 courts are surrounded by an arcade that includes statues of ancient Egyptian gods and goddesses*."

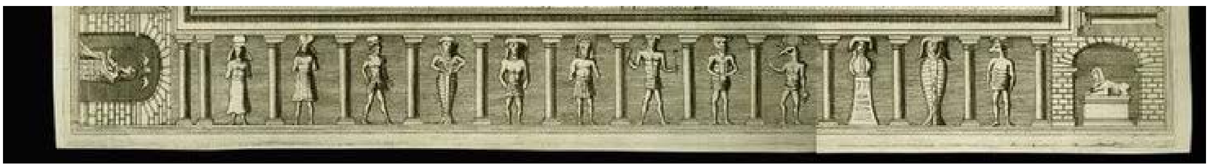


Figure 7.20: The arcade section of Kircher's visualization of the Egyptian Labyrinth as displayed in the virtual reality experience.

The user can then move freely and teleport to other parts of the virtual reality experience.

- *Model 1 - Part 2*

The user can, for example, teleport to this part of Kircher's Labyrinth, which provides more detailed information about one of the nomes, the Nome of Bubastis. This space includes two panels; one of which is used to teleport to other sections of the Labyrinth, highlighted in yellow on the panel (See *Figure 7.21*). The other gives further details about this part of the Labyrinth, including Voice-over 6.

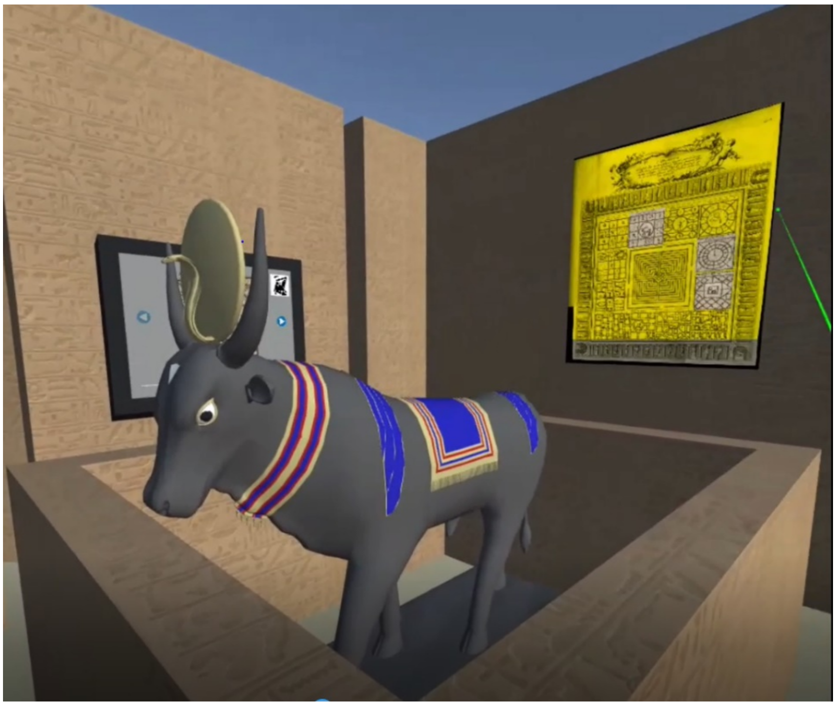


Figure 7.21: Screenshot from the virtual reality teleportation to the Nome of Bubastis

Voice-over 6

"*The Fifth Nome (Nomus V Bubalticus)*

The fifth nome represents the Nome of Bubastis which is also known in Arabic as Tel Basta*. Kircher in his reconstruction represents it as a maze with a cow in the middle*."

As each nome represented a particular city or area, in this case the ancient city of Tel Basta, an image of Kircher's original visualisation is provided, alongside archaeological remains from the city (See Figures 7.22 – 7.24).

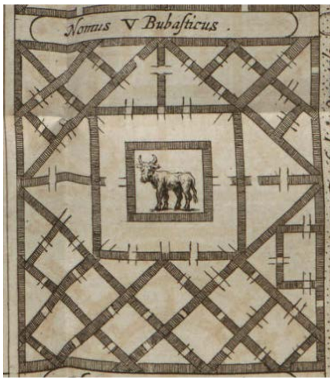


Figure 7.23: Nome of Bubastis section from the visualization by Kircher

Figure 7.22: Tel Basta, Egypt

Figure 7.24:Statue of Horus from Tel Basta

- *Model 1 - Part 3*

Users can also teleport to another nome, the Nome of Thebes (See *Figure 7.25*). The space includes two panels, one for teleportation to other parts of the model, the other providing an explanation for the design of this space, with images and a voice over, as explained below.

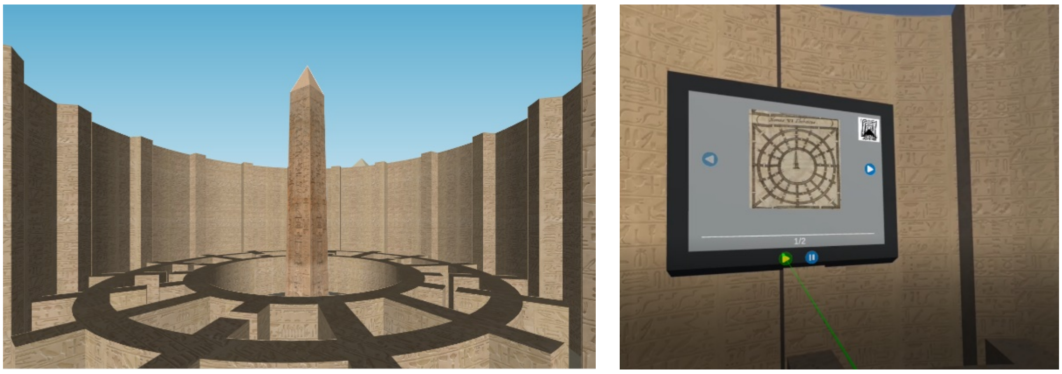


Figure 7.25: Screenshots from the virtual reality teleportation to the Nome of Thebes

Voice-over 7

"*The Sixth Nome (Nomus VI Thebaicus)*

The sixth nome represents the Nome of Thebes. Thebes was the capital of Egypt for long periods during the Middle Kingdom and New Kingdom eras. Its ruins lie within the modern Egyptian city of Luxor. Kircher represented the Nome of Thebes by a circular maze with an obelisk in the middle."

The images provided here include Kircher's visualisation of the Nome of Thebes and an image of the remains of Thebes in the contemporary city of Luxor (See Figures 7.26 and 7.27).

Figure 7.27: Nome of Thebes section from the visualization by Kircher

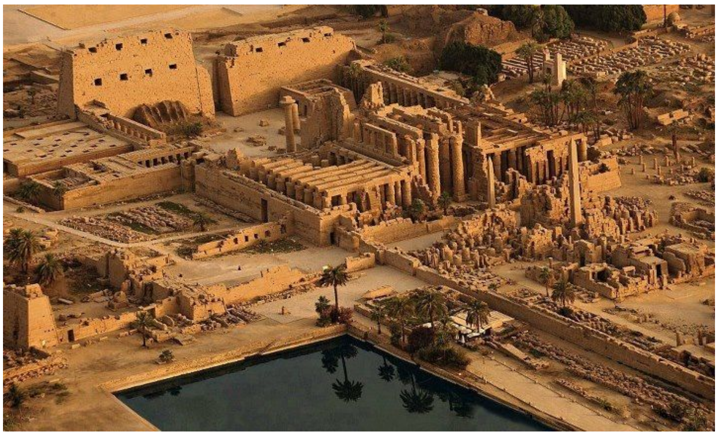


Figure 7.26: Thebes, City of Luxor

- ***Model 1 - Part 4***

The final part of the first model which users can visit is the Nome of Memphiticus (See *Figure 7.28*). As before, users can interact with the panels to teleport to other spaces or to find out more about the space and its symbolism, including Voice-over 8.

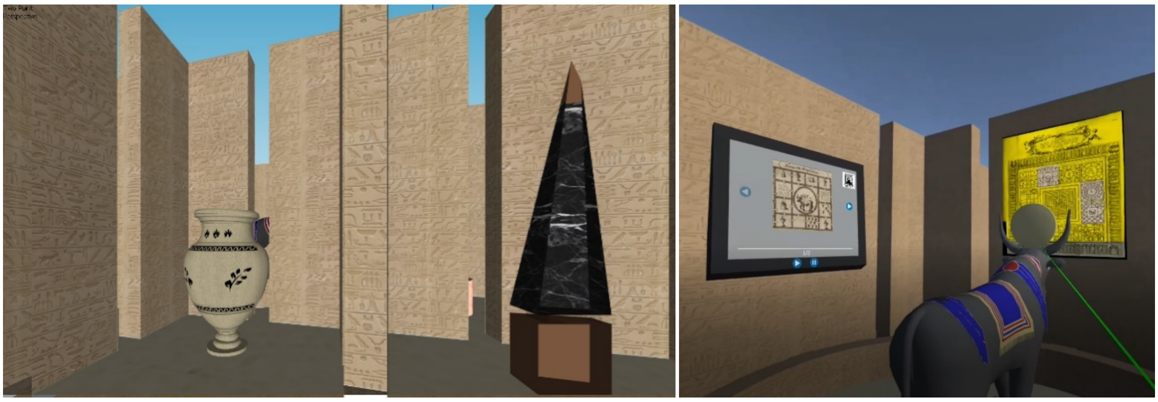


Figure 7.28: Screenshots from the virtual reality teleportation to the Nome of Memphiticus (Memphis)

Voice-over 8

"*The Ninth Nome: (Nomus IX Memphiticus)*

The ninth nome represents the Nome of Memphis or Manf *in Arabic. Memphis was the first nome of lower Egypt. Its ruins are located near the modern town of Mit Rahina. Kircher represented Memphis as a linear maze with a circle in the middle*."

The images provided include Kircher's visualisation of the nome, and the archaeological remains located near Mit Rahina (See Figures 7.29 and 7.30). Once this part has been explored, the user is directed back to the first scene in the museum, where the other models can be accessed.

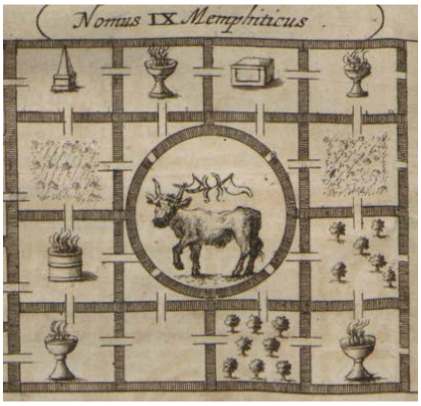


Figure 7.30: Nome of Memphis from the visualization by Kircher

Figure 7.29: Nome of Memphis

- Scene 3: Model 2 (Lucas's visualization)

The third scene of the virtual reality experience introduces the model that represents the reconstruction by Paul Lucas. The user can access this model via the main museum scene (See Figure 7.32). Scene 3 includes a panel with images and a voice-over, and the user moves around the model without needing to teleport into other sections, as this reconstruction includes only one space (See Figure 7.31). The text of Voice-over 9 is provided below.

Figure 7.32: Paul Lucas's model in the museum scene

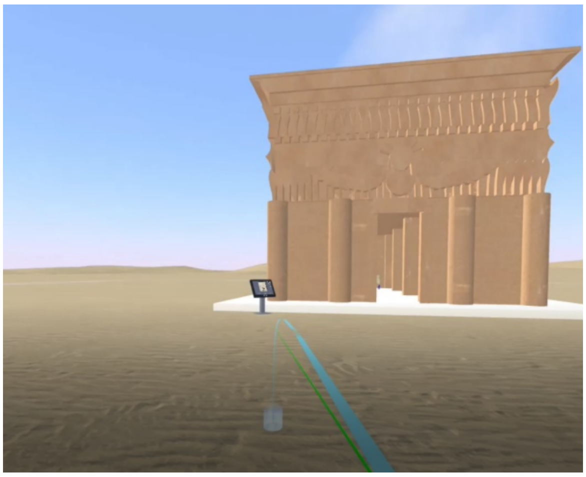


Figure 7.31: Screenshot of the virtual recreation of Paul Lucas's reconstruction of the Labyrinth

Voice-over 9

"*Paul Lucas, the Antiquary to Louis XIV travelled to explore Egypt in 1700, During his visit, he generated an incoherent visual and textual description of the remaining ruins of the Labyrinth. In* *his written description of the Labyrinth, he mentioned that he was accompanied by an Arab who claimed to have explored the inner chambers and passages of the Labyrinth before*."

- Scene 4: Model 3 (Canina's visualization)

The fourth scene introduces the model of the reconstruction based on Canina's visualization of the Labyrinth. As before, the user accesses this model via the main museum scene (See Figure 7.34). However, in contrast to the previous model, in this case the user views the model from above, so the internal structure can be seen (See Figure 7.33). The scene also includes a panel a portrait of Canina, an image of his original architectural plan (See Figures 7.35 and 7.36), and Voice-over 10.

Figure 7.34: Canina's model in the museum scene, showing how the user teleports to the larger scale model.

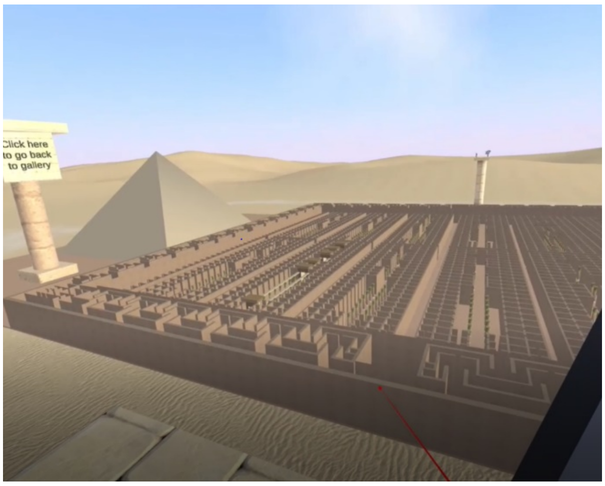


Figure 7.33: Screenshot of the aerial view of the model showing the labyrinth structure

Voice-over 10

"*Luigi Canina was an Italian architect and archaeologist. Canina developed a visualization of the Labyrinth, including 12 similar courts with three open spaces with columns inside. The 12 courts are surrounded by maze like structures. Canina is well known for his studies of history and archaeology and this visualization was part of his published work " Ancient Architecture Described and represented in documents". Luigi Canina never visited the actual site of the Labyrinth and this visualization was based on accounts of Greek authors such as Herodotus.*"

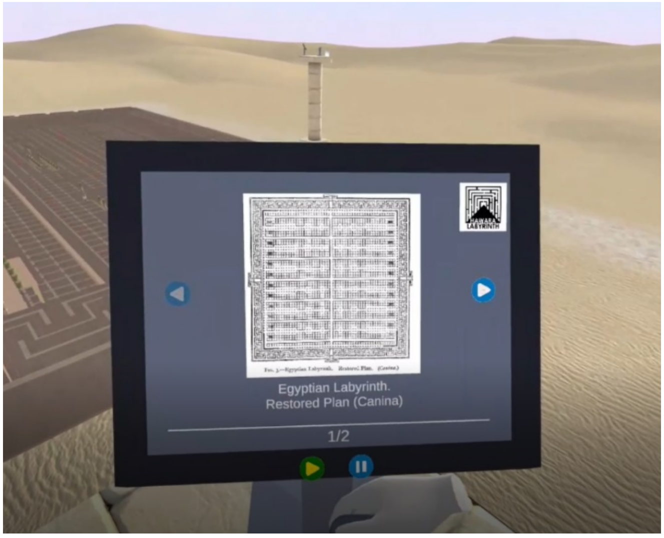


Figure 7.35: Screenshot showing the architectural plan of the labyrinth by Luigi Canina

Figure 7.36: Portrait of Luigi Canina used in the virtual reality experience panel. Source: https://www.ribapix.com/Luigi-Canina_RIBA5820

- *Model 3: Part 2*

Canina's visualization includes 12 courts (or nomes) surrounded by a maze-like structure. By clicking on the teleportation signs within the model, the user can move inside one of the chambers of the Labyrinth (See Figure 7.37). The space is typical of those Canina created based on previous historians, as mentioned earlier. However, columns, pylons and textures have been added to make the space more visually appealing to the general public than Canina's two dimensional image.

Figure 7.37: Screenshot of one of the 12 chambers in Canina's model within the virtual reality experience

7.6 Virtual Reality Experience Development

Once the scenario explained above had been devised, the development of the actual virtual reality experience was completed. As explained previously, this firstly involved the creation of the three dimensional models, then the scenario was designed, and all the necessary media, including the images, text, models and voice-overs, were assembled, ready to be integrated into the virtual reality experience. The following section explain the technical equipment which was used to integrate all of this information into a virtual reality experience, beginning with the VR headset.

- Virtual Reality Headset

The first step included choosing the VR headset for the virtual reality experience. This choice was made depending upon the availability of headsets, the budget and the experience requirements. The headset that was chosen is the Oculus Go, which is characterized by being a standalone, all in one virtual reality headset. This means it does not need to be connected to other devices in order to run the virtual reality experience. Developed by Facebook technologies in partnership with Qualcomm and Xiaomi, it was first released on the 31st of May 2018. It is equipped with a 5.5 inch LCD display screen with a resolution of 1280 x 1440 pixels per eye and a fresh rate of 72 or 60 Hz. The headset uses the Android mobile app operating system (Wikipedia, 2021).

Figure 7.38: Oculus Go VR Headset
Source:
https://enstock3o.top/products.aspx?cname=oculus+go+airpods&cid=146

- Virtual Reality Platform and SDK (Software Development Kit)

The Oculus virtual reality platform was chosen as it is compatible with both the Oculus Go and later generations, such as the Oculus Quest. As for the SDKs (software development kit), the VRTK (Virtual reality tool kit) was used. VRTK is a collection of scripts and concepts that are already included in VR libraries, and these help to build VR solutions faster. It includes a number of common solutions, such as locomotion[7] within the virtual space, several interactions, like touching, grabbing and moving objects, interacting with unity 3D elements through pointers and touch, and 2D and 3D controllers, such as buttons, levers, and doors etc (VRTK, 2021). The VR engine used in Unity.

Table 7: VR Platform and SDKs Used

Platform	Oculus	
SDK (Software development Kit)	VRTK (Virtual Reality Tool Kit)	Used for testing Oculus features inside the Unity game engine.
	Oculus SDKs	Used for allowing VR mode to work properly on VR headset
VR Headset	Oculus Go	
VR Engine	Unity	

[7] In this context, 'locomotion' refers to the act or ability of something to transport or move itself from one location to another.

- Optimization of 3D Models for VR Using Blender Software

The main purpose of the optimization of the assets used in the virtual reality experience is to give users the best experience. It is generally recommended that, for the best user experience, the model should have less than 200k polygons and include no more than 16 texture maps with a resolution not larger than 2048 x2048 px. These recommendations change with time and software development; however, an optimization of the original models for the Labyrinth was needed to avoid a delay in real time rendering through the virtual reality experience (BRIO, 2021) Due to the high degree of detailing and the size of the 3D models, it was essential to minimize the details and decrease the number of polygons. This was done by using Blender software. Blender is a 3D modelling software that is widely used with virtual reality experiences. Although the Unity game engine has the capacity for developing 3D models, it does not offer the same flexibility and detailing as more specific 3D modelling software, such as Sketchup and Blender. Screenshots of the optimization of the Kircher and Lucas 3D models using Blender are shown in Figure 7.39 - 7.42.

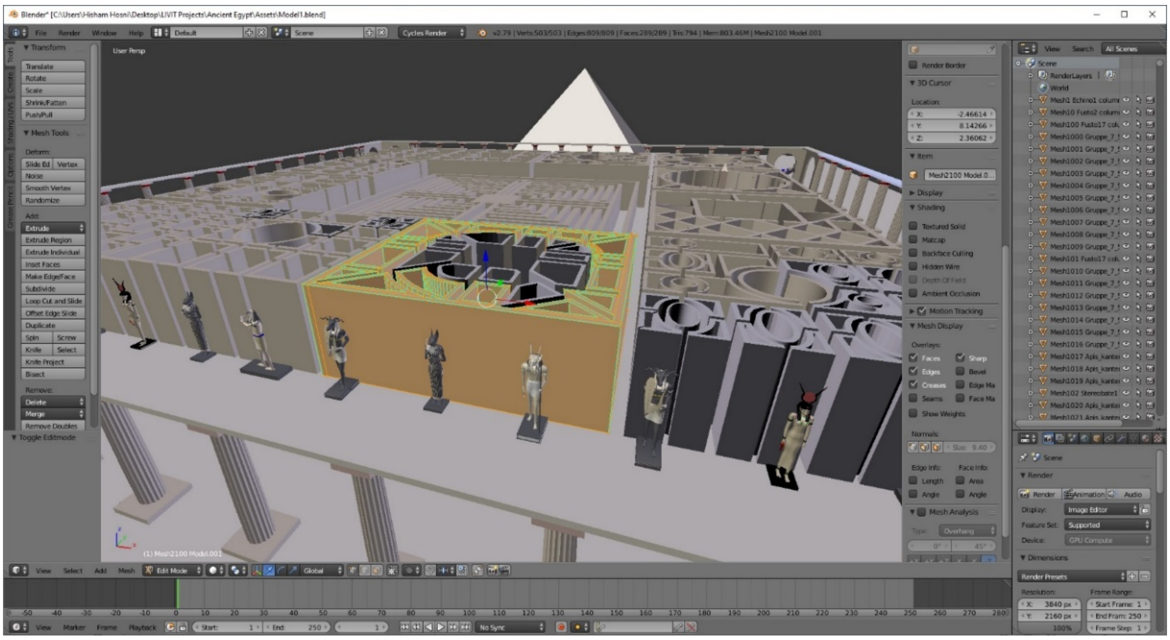


Figure 7.39: Screenshot of the optimization of the Kircher 3D model in Blender

Figure 7.41: Screenshot of the optimization of the Paul Lucas 3D model in Blender

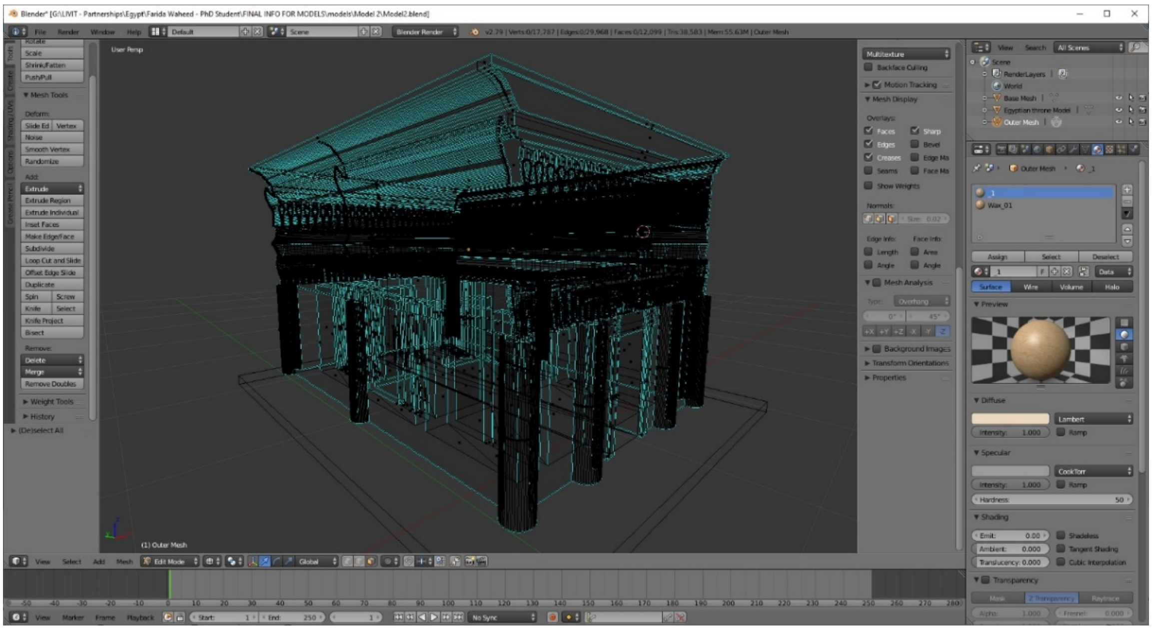


Figure 7.40: Screenshot of the Blender application used for optimization for Paul Lucas 3D model in wireframe

The optimization process also included the creation of several smaller models from the main model. This was done specifically with the visualization by Kircher as the model size was very large in comparison with the other two and included several teleportation options. This required having a less detailed version for the main entrance scene, with more details in each of the different spaces. As a result, the models that were used in the main museum exhibition space were the initial models which just included the general layout, without any details. The optimization also included changing the scale of the models, bringing them down to a more human scale that would be acceptable to users.

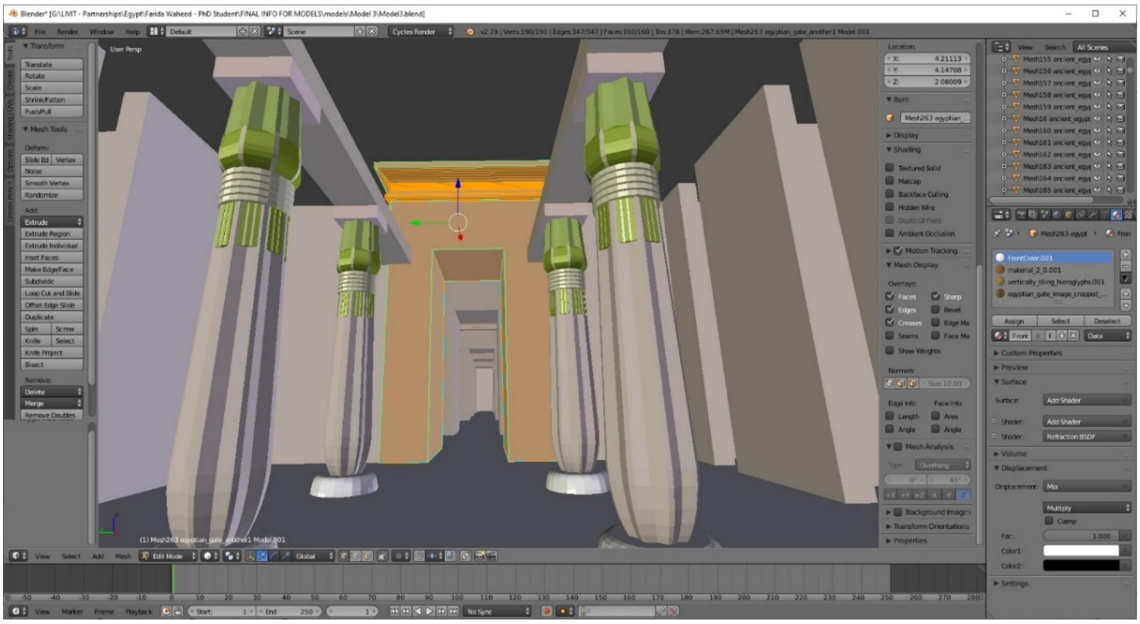


Figure 7.42: Screenshot of the optimization of the Canina 3D model in Blender

- Virtual Reality Experience Unity 3D Development:

In order to create a virtual reality experience using Unity, the four scenes (Gallery Scene, Model 1, Model 2 and Model 3) needed to be prepared and structured within the same project file. After the scenes were created, the VR environment that was selected for the experience was added. The VR environment included the surrounding landscape as well as the sky and lightning that was used in order to make the virtual experience as real as possible. The VR environment was then imported into the project. This step was followed by importing the 3D models that were previously optimized using Blender software. The models were then moved and placed inside the Unity game engine as required in the different scenes.

Once the models were in their required locations, VR interactions for the teleportation and selection were added. This involved using scripts to create functionality for the panels in order to be able to teleport and to select different actions, such as moving from one slide to another as well as to play the various voice-overs. The next step was adding the voice-overs, which had previously been recorded by the author, as well as the selected images to the experience. Once all the main assets were added, as well as the plugins and codes, the whole experience had to be optimized for the best performance on the Oculus Go headset. The transitions from one scene to another were then finalized and the application was ready for testing on the headset. The while process can be summarised as follows:

Basic steps for developing the VR experience:

2. Select a VR headset for the Project.
3. Optimize 3D models for VR using Blender and Unity game engine.
4. Add the plugins needed for the project.
5. Prepare and structure the scenes.
6. Create and import the VR environment used in the project.
7. Import 3D models into the game engine then place them as required.
8. Add VR interactions for teleportation and selection inside the VR experience.
9. Add sound effects to the environment and VR interactions.
10. Add voice-over and images into the VR experience.
11. Scene optimization for optimal performance on the VR headset.
12. Create transitions between scenes.
13. Test the application.

The screenshots below show how the various elements were added to each scene using the Unity game engine to create the final virtual reality experience (See Figures 7.43 – 7.46). The first image demonstrates the different textures used in the tab below.

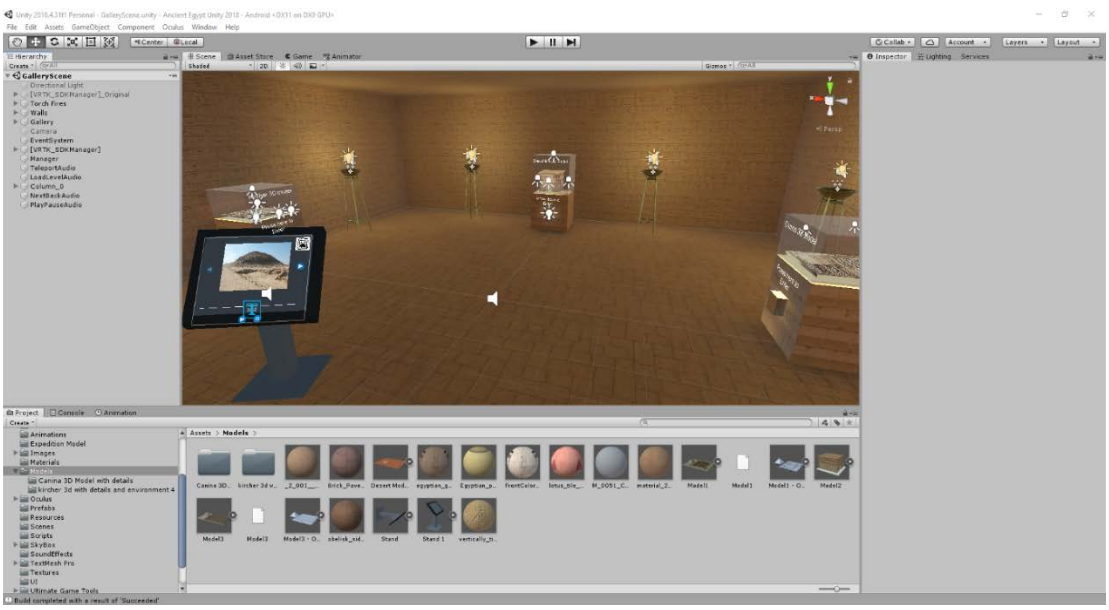


Figure 7.43: Gallery Scene screenshot from Unity game engine showing adding the voice overs as well as the lighting

The following images figure (46-47) show the elements of the 3D model and the textures used in the three different representations of the Hawara pyramid and Labyrinth. The different scenes are created as separate models and the navigation between the different scenes takes place through the interactive features of the virtual reality experience.

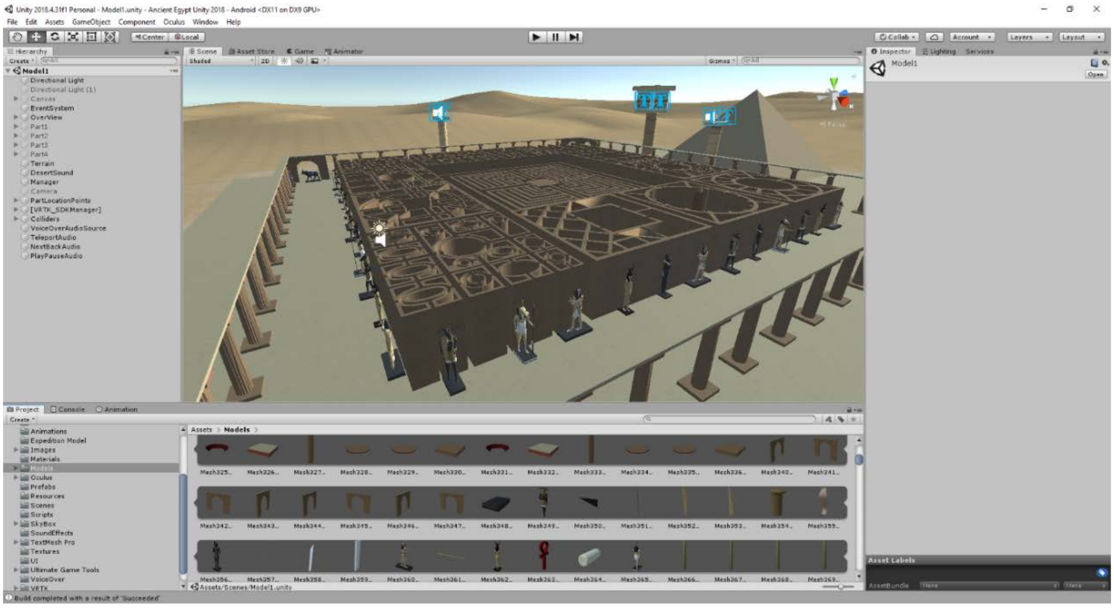


Figure 7.44 Screenshot from Unity game engine for Kircher's model

Figure 7.44: Screenshot from Unity game engine for Paul Lucas's model

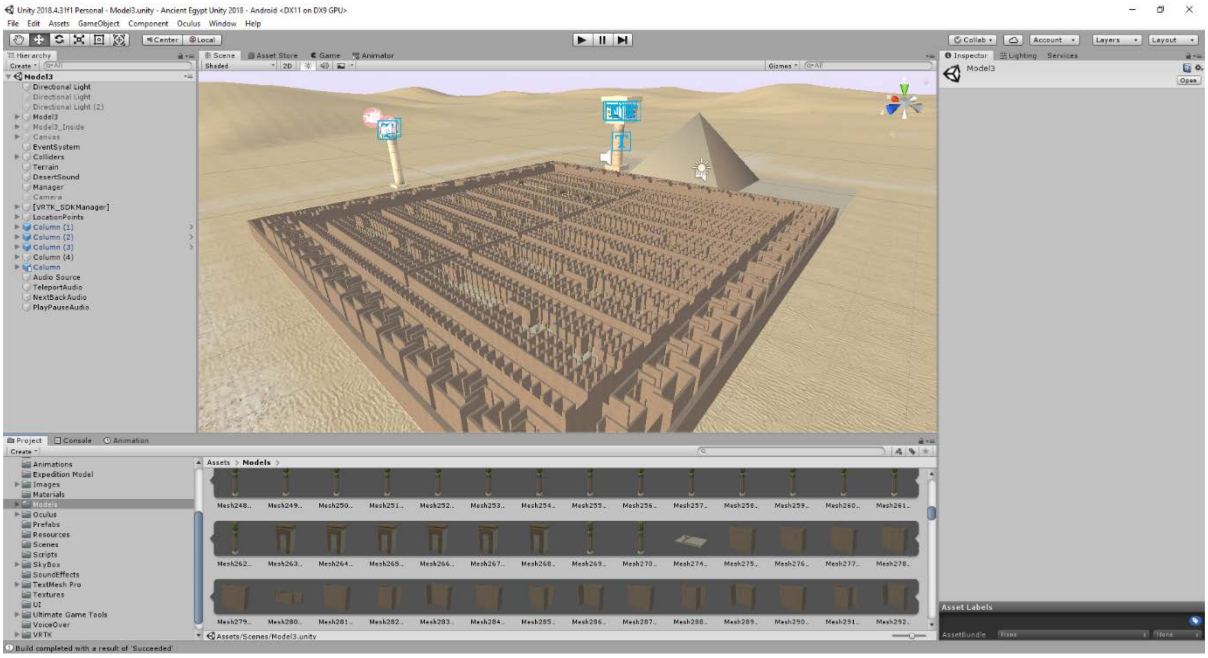


Figure 7.45: Screenshot from unity game engine for Canina's model

The interactivity is activated into the models using coding. The screenshot below demonstrates the scripting that was used in developing the virtual reality experience.

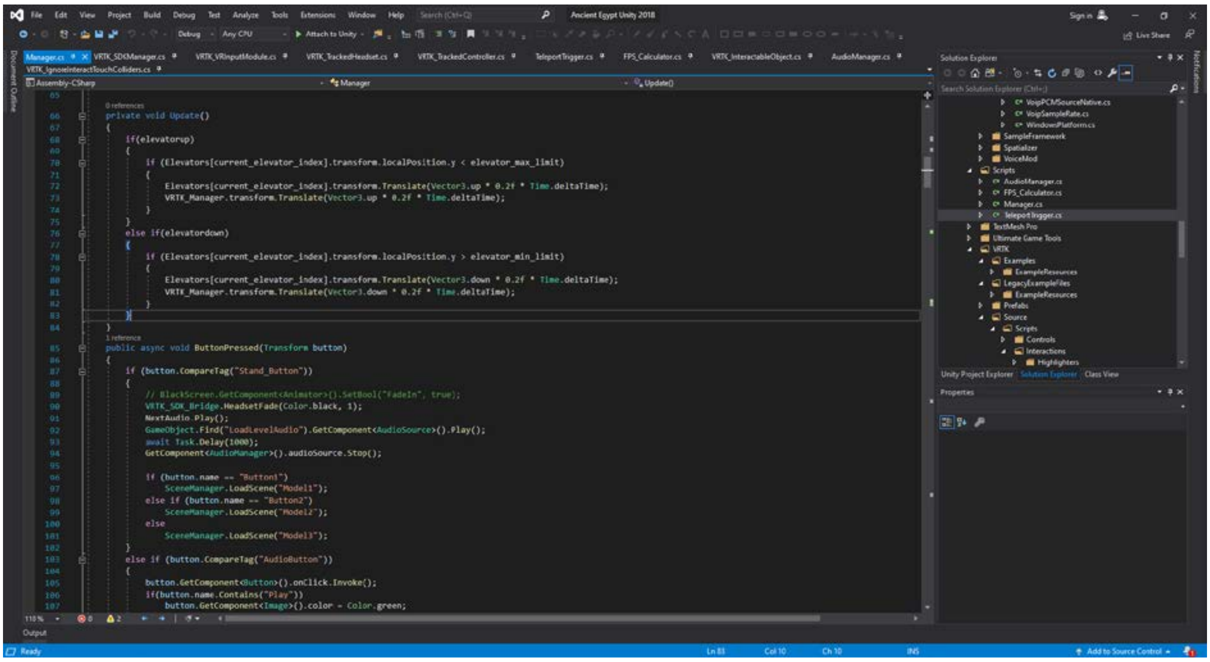


Figure 7.46:Code Snippet from VR experience interaction

7.7 Virtual Reality Experience Demo

In order to demonstrate the final outcome of the virtual reality experience a demo is created. The demo of the virtual reality experience presents the teleportation throughout the experience and exploring the three different reconstructions from different view. In order to view the full experience please follow the below QR code.

In order to elaborate more on the sequence of the virtual reality experience the following story board is created. It focuses on exploring one of the three models presented within the virtual reality experience. It shows how the user is presented by a museum space where she/he is able to teleport through clicking on three different small-scale models of the three virtual reconstructions in order to walk through the reconstructions and view them in details from different views.

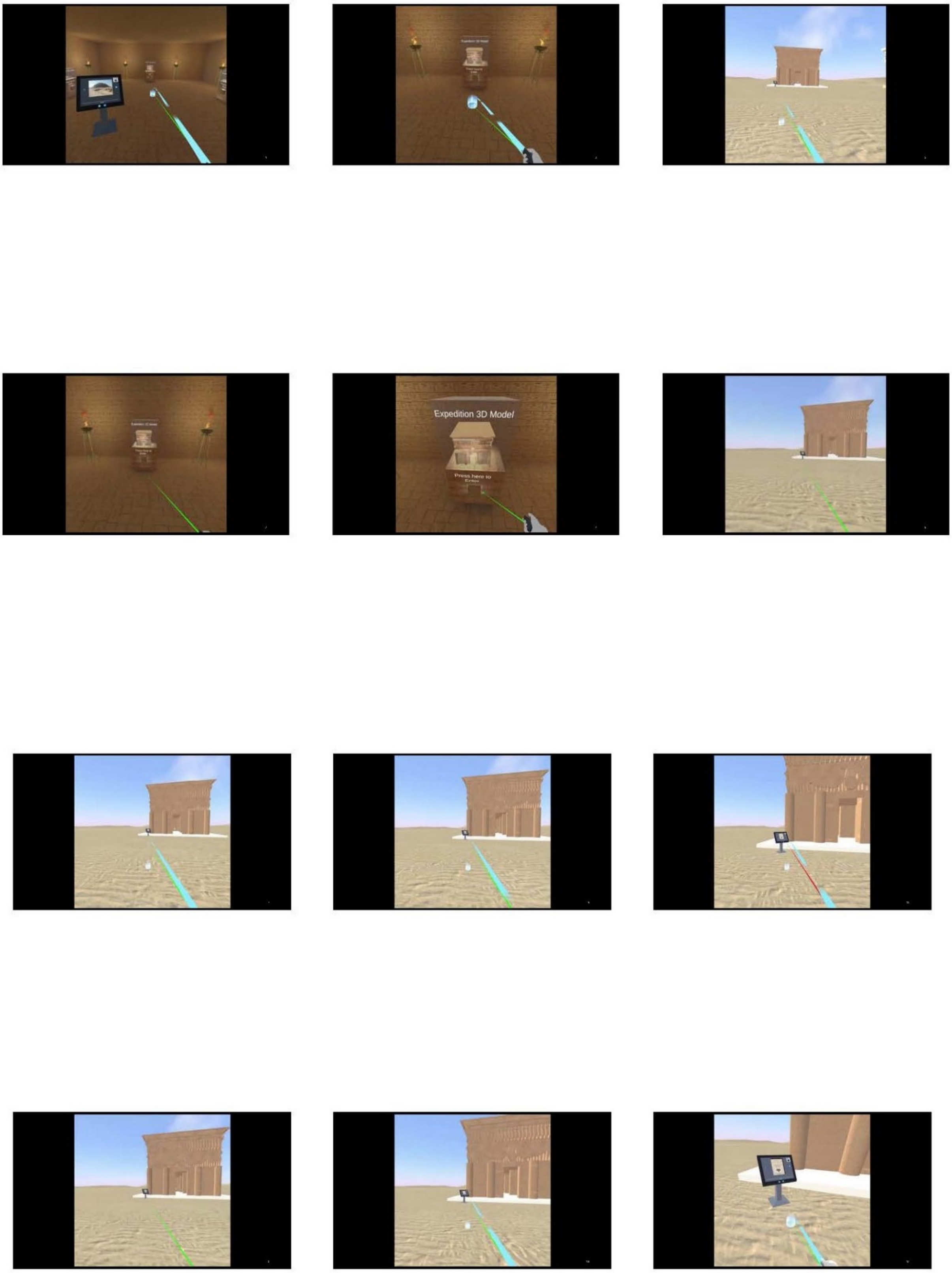


Figure 7.47 Virtual Reality Experience Story Board 1

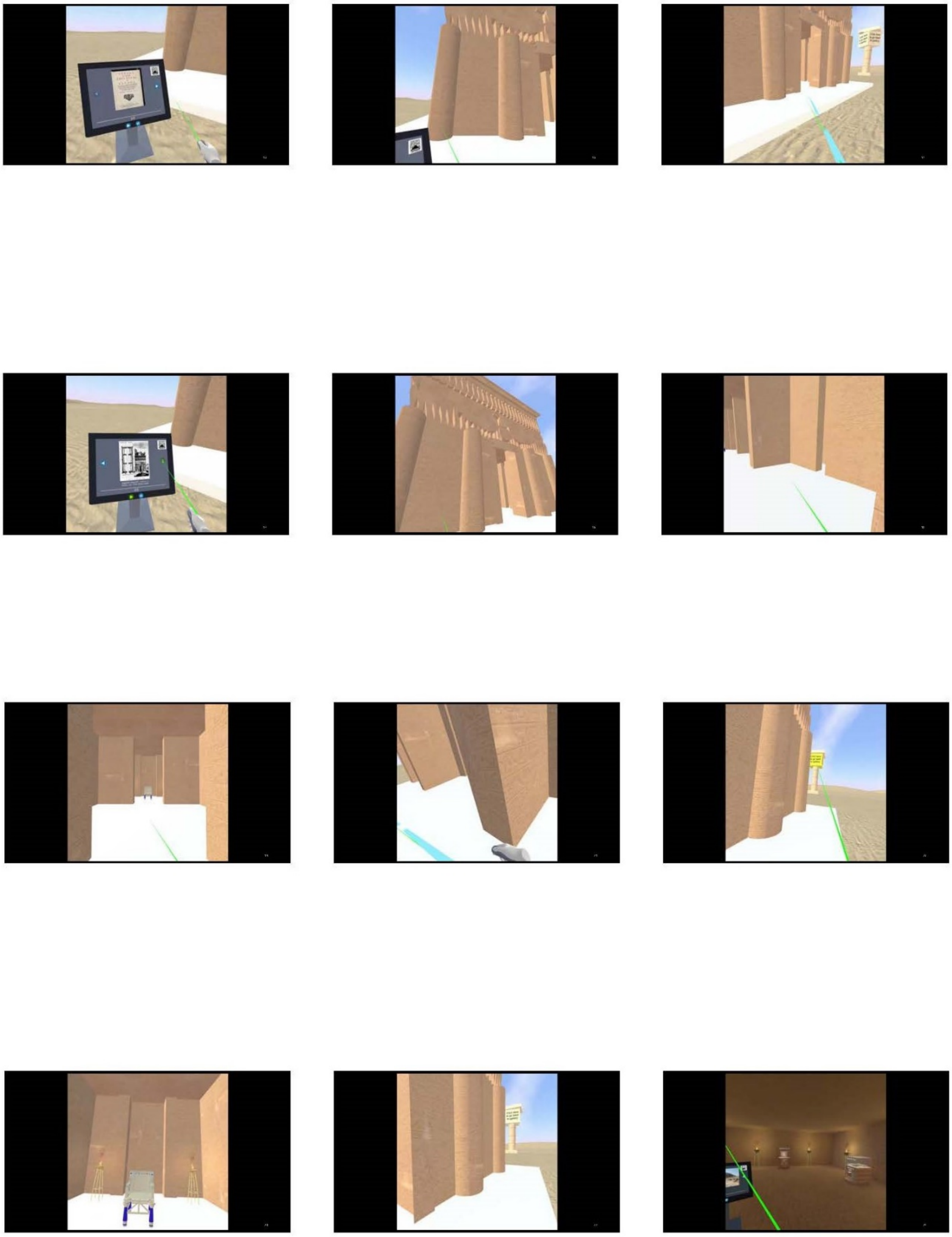


Figure 7.48: Virtual Reality Experience Story Board 2

7.8 Conclusion

This chapter has provided a detailed description of the process undertaken by the researcher to develop a virtual reality experience. The aim of generating this experience was to test the ability to present the subjectivity and uncertainty inherent in digital archaeological reconstructions. The scenario for the virtual reality experience was first created as a draft and developed over time, and the amount of detail within the models was changed to give the users the best possible experience. Using Sketchup as an initial modelling software was easy and quick way to convert the two dimensional images into three dimensional models; however, optimizing the models to be suitable for a virtual reality experience was more difficult. Although software which is specifically designed for virtual reality experiences is available, it was not intended to be used for architectural reconstructions. As a result, the researcher found that the best 3D external modelling software to use with Unity were Autodesk Maya, 3Ds Max, Blender, Sketchup and ZBrush.In this research work the softwares that were used are Blender and Sketchup. The challenge of optimizing the model indicates the importance of investigating the most suitable software for the aim of the project and the size of the model in similar research work in future.

The virtual reality headset was chosen based on suitability, affordability and availability. It was found to be suitable both for research testing and for use in museums or archaeological sites. As rapid advances in technology mean new, higher performing headsets are produced every year, it was judged best to design the virtual reality experience to run on a platform such as Oculus that has new generations. This means that, with changes in technology the virtual reality experience can still be useful for years after its design but with better performance with new upgraded headsets from the same company. One of the most important steps undertaken before achieving the final model was performance testing of each 3D model, and some adjustments were made during the process. Performance testing was done using Blender and Unity 3D to test the size of each model and how this would affect performance on the VR headset. Optimization using Blender and Unity was also done for each 3D model to ensure performance was acceptable on the VR headset.

The choice of the most appropriate rendering style to represent the uncertainty of digital archaeological reconstructions was challenging within this process. The use of a non-photorealistic style, with transparent or multicoloured parts and sections, was not chosen as it was considered unsuitable for use with the general public. However, the level of photorealism within the models was not considered very high, especially as users explore the layout of the buildings from a bird's eye view first. The users are exploring the visualizations in a way that would not be possible in a real temple or labyrinth, and this was especially challenging with the visualizations by Kircher and Canina. However the researcher attempted to present both a bird's eye view and a human scale view so as to create a different experience for the users. It cannot be denied that even the most photorealistic virtual reality experiences still give a version of the reality in a different setting. This could be a solution as well as a challenge. The fact that users can fly over the virtual building gives them a different understanding of their layouts and creates a sense of illusion and non-reality, which aids in perceiving and understanding that this reconstruction is partially really and partially imagined by the experts. However, the integration between real images and imaginations achieved in the virtual experience is believed to increase users' awareness of the site and to enrich their experience, leading to a better understanding of its history and archaeology.

The next chapter describes the process of testing the virtual reality experience with users, namely members of the general public in selected venues. This was essential to assess both its usability and the perceptions of the users to establish its effectiveness and to provide recommendations for future development of similar virtual reality experiences. The experience testing was considered the last phase of this research work. This completes the in-depth exploration of the subjective uncertainty of digital archaeological reconstructions, starting from a theoretical point of view to in-depth analysis of experts' views and best practice and then on to the more technical and applied understanding through developing the virtual reality experience.

8. CHAPTER 8: EVALUATING THE VIRTUAL REALITY EXPERIENCE

8.1 Introduction

This chapter includes the last section of the research. The main aim of the chapter is to evaluate the effectiveness of the virtual reality experience that was detailed in the previous chapter. In order to achieve this, it was essential to test the experience with a range of users. A total of 52 participants took part in the evaluation and completed a Likert scale survey, which addressed several critical points within the virtual reality experience. Their feedback provided an additional layer of understanding of how users would perceive the subjectivity of digital archaeological reconstructions, and data for future development of similar virtual reality experiences. The trial took place in Egypt as the case study was also conducted in Egypt, so this was applied within the same cultural context. Virtual heritage being one of the technologies that is being utilized and researched to be used within the Egyptian context is evaluated within this chapter. Previous research work as well as on site projects have been exploring the use of virtual reality in archaeological sites and museums in Egypt. (Farid and Ezzat, 2018; Heritage Innovation Preservation (HIP) Institute and Faculty of Engineering Cairo University, 2015). However this approach is still considered quite novel within the Egyptian context and the users are not widely acquainted with such technologies. The virtual reality experience not only tests the possibility of integrating such technology within the general public in the Egyptian context. It also explores the more complex experience of providing several interpretations for the same archaeological site. It will be clear through exploring this chapter that the evaluation tests the virtual reality experience in terms of quality and usability. Through this the users are asked about their opinion regarding the interface and providing several reconstructions. In addition to that the users will be asked a set of questions to explore in depth analysis regarding the issue of subjectivity which is the main aim from this research.

8.2 Survey Design

The aim of the survey was to gather data from test participants to get an insight into how they perceived the virtual reality experience and also to analyze the usability of the experience. In order to design the questions for the survey, a survey on evaluating virtual and augmented reality experiences was examined along with the previously discussed literature. The most important criteria for assessing the user experience in virtual reality experience were found to be *presence*, *engagement*, *immersion*, *flow*, *skill*, *emotion*, *usability*, and *technology adoption* (Tcha-Tokey et al., 2016). It was also important to refer to surveys that explore the use of virtual reality in the field of archaeology to explore how the questions there were designed (Augmented Reality Questionnaire, 2021) However, while such surveys informed the design of this questionnaire, the questions were simplified to make them more suitable for the general user. As they were asking non-specialist users about the subjectivity of digital archaeological reconstructions or the usability of a virtual reality experience, they needed to be in a simple format for users to be able to answer them properly. For example, regarding skills, respondents were asked if they thought they would become more skilful in using virtual reality over time or not. As for the emotion element, users were asked about enjoying the experience as well as being fearful of it. Participants were also asked about the usability of the experience and the interface. The following section explains how the experience was tested and provides further details about the participants.

8.3 Virtual Realty Experience Testing

The virtual reality experience is aimed at members of the general public. Although the experience targets a range of general users, the voice-overs in the prototype were in English, so it was essential that participants had some understanding of English. It was also not possible to allow children to participate in the survey as they may not have had the capability to answer the questions. As a result, four different locations in Cairo were selected for the virtual reality experience testing, all of which were likely to attract English-speaking adults. The first was Cairo University, the second a coffee shop in Zamalek, the third a coffee shop in New Cairo, and the fourth location was at the TurnKey Expo, in Madinet Nasr. The first three locations were used for sample testing before the largest sample was collected at TurnKey Expo.

Figure 8.2: Photo showing the entrance to TurnKey expo

Figure 8.1: Photo showing one of the users testing the virtual reality experience in the booth at TurnKey Expo

The experience was tested by asking random participants to contribute to the evaluation, and the target number was 50 participants. The survey form is attached in Appendix (A.2) However, in each of the first three locations, the number of participants was no more than 10, and this indicated the need to find a venue with a larger number of potential recruits. As a result, the researcher booked a booth in the Turnkey Expo to test the experience with a larger sample of possible users see Figures 8.1 - 8.2 . The expo is an interior design event, open to the public, and it included several companies showcasing different construction and interior design materials. The sample was chosen randomly and mainly depended on users approaching the researcher to try the virtual reality experience. The final number of participants was 52 across all four venues, from a range of backgrounds; however the largest number of participants were university students. Further details about the participants are provided in the following sections.

8.4 Demographic Data

The following questions covered the demographic data that was collected as part of the analysis of the survey. The demographic data included the age group,the level of education, Job/education in order to have a better understanding of the sample group.

8.4.1 Age Group

The first section asked respondents for some basic demographic information. The first question was regarding the age of the respondents. The majority of the sample fell within the 20-29 age group (69.2%), with 13.5% within the 30-39 age group, and 11.5% within the 15-19 age group. A small percentage of respondents (3.8%) fell within the 40-45 age group, and just 1.9% were aged 60-69 (See Figure 8.3). This might be due to the fact that the experiment was undertaken in three locations which typically attract younger people (Cairo University and the coffee shops); however, it might also indicate that older or younger people might not be as attracted to such experiences. As explained above, children were not targeted while gathering the data samples.

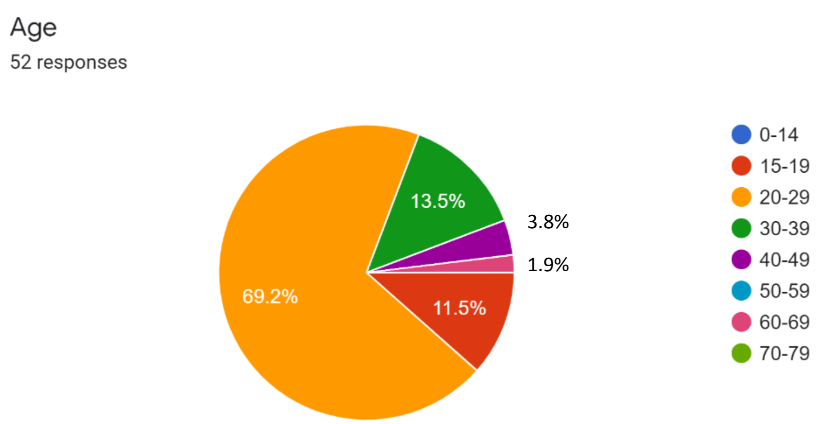


Figure 8.3: Age Groups of Participants

8.4.2 Level of Education

The following question was asked about the level of education of the participants. This was important because users needed to be educated and to have a basic knowledge of English in order to understand the narration in the virtual reality experience. 65.4% of respondents held bachelors' degrees, and 23.1% master's degree. Just under 10% held middle or high school certificates and 1.9% were PhD holders (See Figure 8.4).

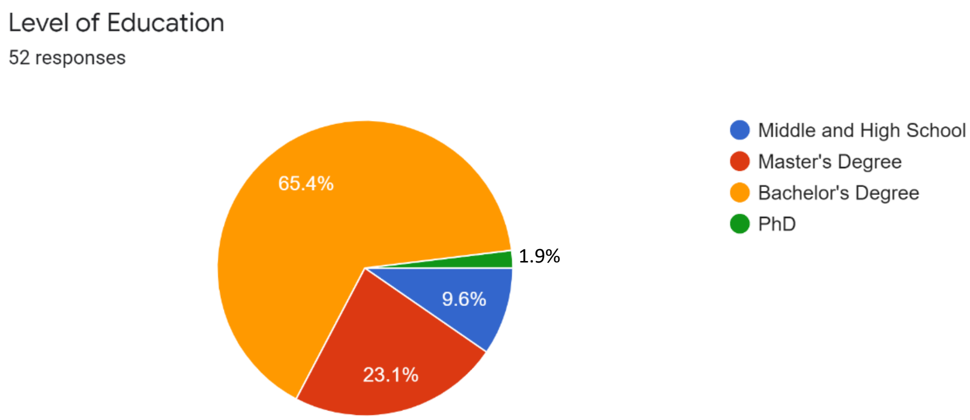


Figure 8.4: Level of education of participants

8.4.3 Job/Education

The next question asked about the participants' educational backgrounds or current jobs. This was important to ensure there was a good variety within the sample. As the main sample was gathered at an interior design and materials exhibition, the largest group of users were from an architecture and construction background (21.3%), followed by education and training, creative arts and design, and engineering and manufacturing, all at 12.8%. Other areas included health care, sports and leisure, tourism, accountancy, banking and finance, business management and administration, government and public administration, political science, physical education and non-governmental organizations and humanitarian work (See Figure 8.5).

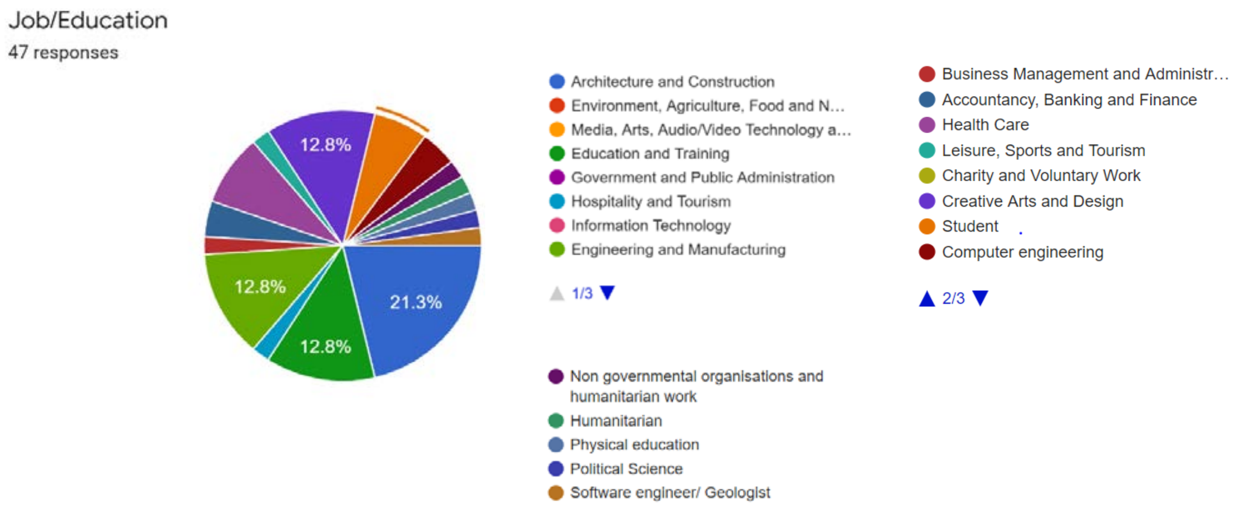


Figure 8.5: Job/ Education of participants

8.5 Previous Experience with Virtual Reality and Archaeology

In order to create a better understanding of the survey sample, four questions were asked regarding respondents' previous experience with both virtual reality and archaeology. Participants were asked how they would classify their knowledge of archaeology and about using virtual reality and whether they had experienced virtual reality before. The majority of respondents (63.5%) said this was their first time trying virtual reality; however, a good number (36.5%) had tried it before (See Figure 8.6). This indicates that virtual reality is becoming more common within the Egyptian community. In addition, while they were trying the virtual reality experience, some respondents mentioned that they had used virtual reality in gaming, but not in applications related to heritage and archaeology.

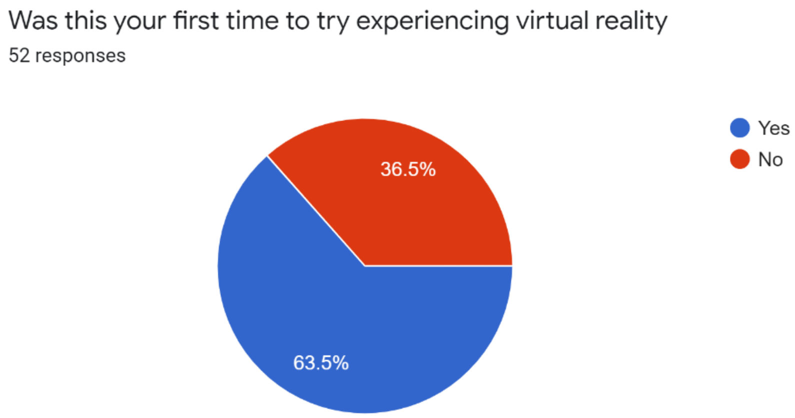


Figure 8.6: Participants' previous experience of virtual reality

Respondents were asked to rate their level of knowledge related to archaeology using a five-point scale, where 1 indicates very good knowledge and 5 indicates very poor knowledge. As can be seen in Figure 8.7, there was a diversity in the responses with the largest proportion (36.5%) rating their level of knowledge as average, and 28.8% considering themselves as having a very good knowledge of archaeology.

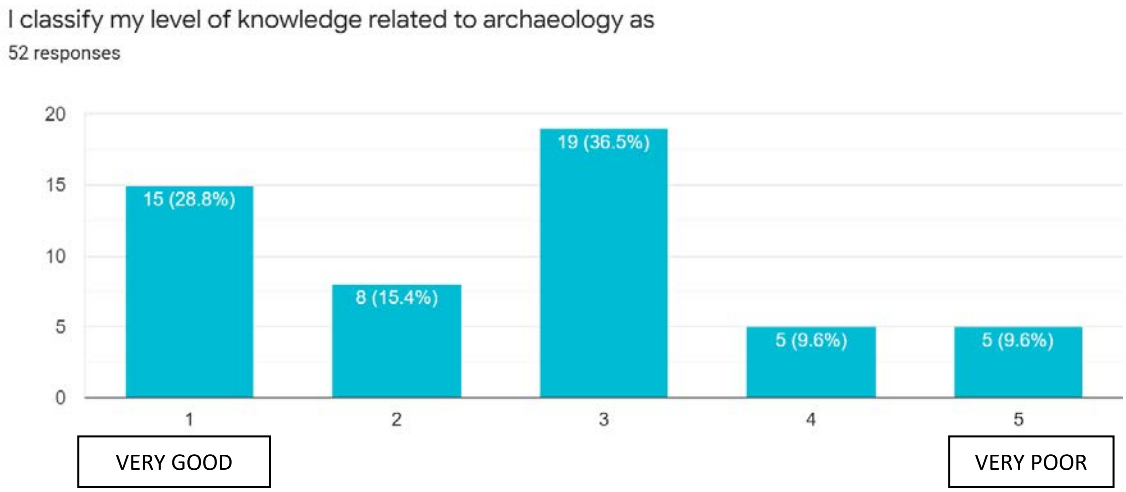


Figure 8.7: Level of participants' knowledge of archaeology

In respect of their level of knowledge about using virtual reality, the largest percentage of respondents (32.7%) reported having an average level of knowledge; however, almost 48% rated their level as very good or good, which is which is a very high percentage (See Figure 8.8). This indicates that the average user in the sample had a reasonable awareness of virtual reality, even if they had not actually used it before.

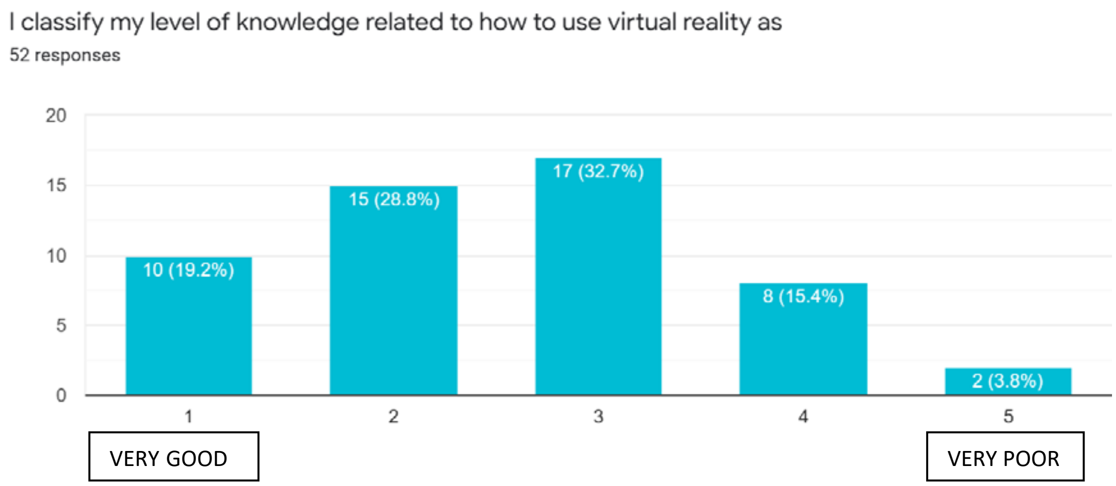


Figure 8.8: Level of participants' knowledge of how to use virtual reality

8.6 Using Virtual Reality for Reconstructing Archaeological Sites:

The next set of questions explored users' opinions on using virtual reality as a media for reconstructing an archaeological site. These questions sought to establish whether they thought using virtual reality added value to the archaeological site, regardless of where the virtual reality experience will be used, with a later set of questions asking about using virtual reality experiences at archaeological sites and museums.

The first question was related to whether or not users thought virtual reality might assist with getting further information about the reconstructed site. Again a five-point scale was used, where 1 indicates agree and 5 strongly disagree. As Figure 8.9 shows, 78.8% of respondents strongly agreed and only 1.9% strongly disagreed.

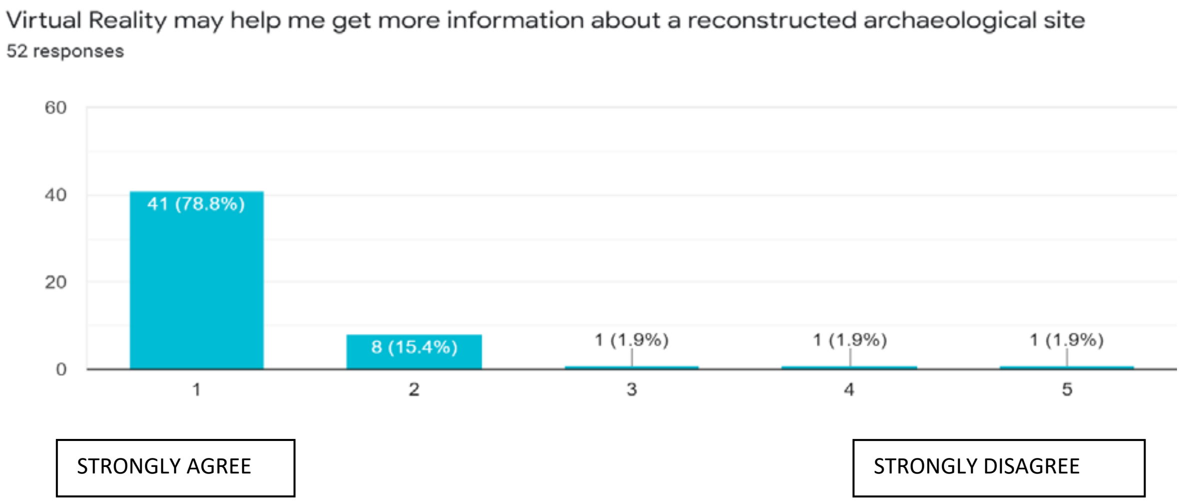


Figure 8.9: Getting more information about a reconstructed archaeological site using virtual reality

The next question asked respondents whether they thought using virtual reality would help them access information about an archaeological site more quickly. Again, the vast majority of respondents (75%) strongly agreed, with this, while just 3.8% disagreed or strongly disagreed (See Figure 8.10). This was tested through the virtual reality experience by exploring the use of interactivity and multimedia such as text, voiceovers and images.

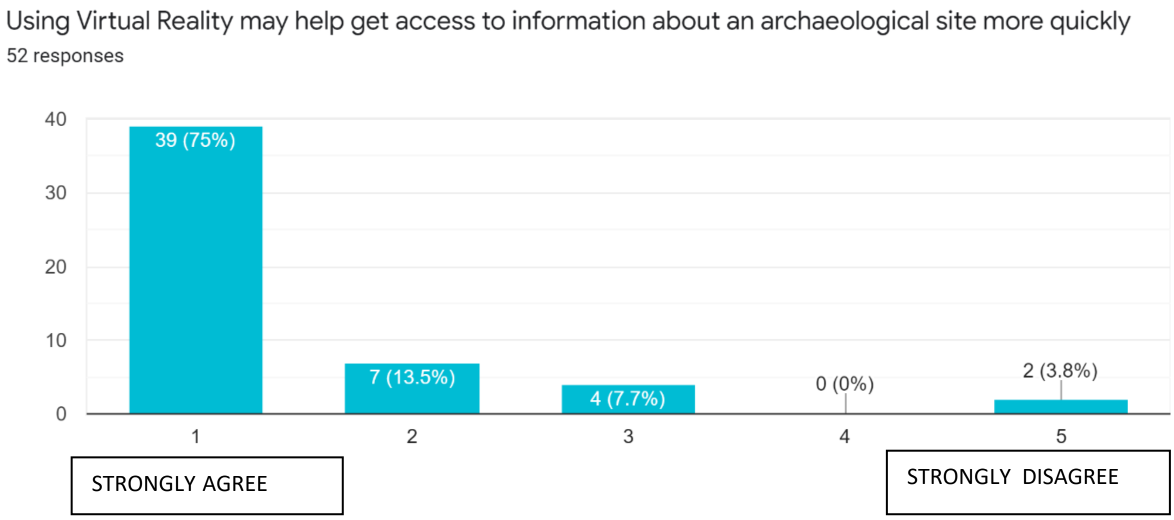


Figure 8.10: Using virtual reality to access information about an archaeological site more quickly

The respondents were also asked if they believed using similar virtual reality experiences would increase their interest in archaeological sites. As shown in Figure 8.11, 75% of respondents agreed or strongly agreed, with just 2% disagreeing or strongly disagreeing. This indicates the significant potential of using such technologies to better inform users about archaeological sites.

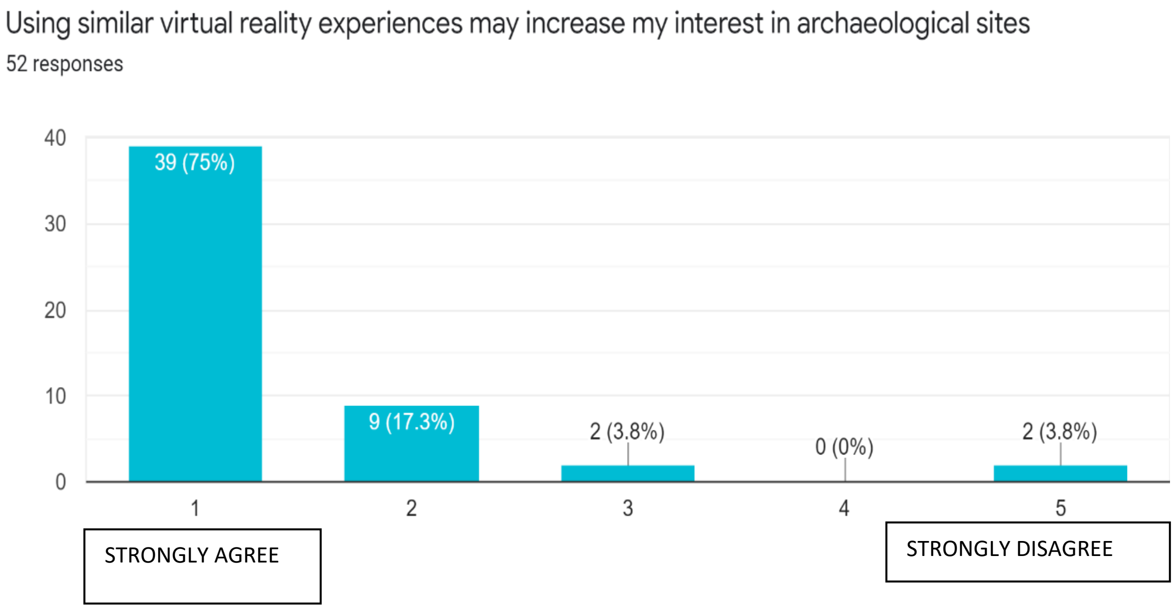


Figure 8.11: Virtual reality increasing interest in archaeological sites

These responses suggest that virtual reality experiences are believed to provide large amounts of data about an archaeological site within one single platform, offering a faster mean of finding the information than other media, such as physical panels, books, internet etc. In addition to this, the use of virtual reality appears to create and increase interest in archaeological sites. As we are in the digital age and users are becoming more interested in digital media, these findings suggests that the incorporation of technology in the field of archaeology will become increasingly important.

8.6.1 Usability of Virtual Reality Experience

Users were also asked about their opinion of the usability of the virtual reality experience. This is a specific evaluation regarding the experience which is intended to explore any difficulties the users might have faced for future improvement of the experience. During testing, users were guided through the experience by the researcher and required some orientation regarding how to use it. This indicates that having such experiences at museums or archaeological sites might mean assistance is available at all times, unlike with other more conventional means of displays.

The first question asked participants whether they thought the virtual reality experience was easy to use. As can be seen in Figure 8.12, there was general agreement that the experience was easy or at least relatively easy to use, with 50% of respondents strongly agreeing and 34.6% agreeing. Just 5.8% disagreed, and 0% strongly disagreed. This is good indicator that, even though not many respondents had previous experience with virtual reality, they did not find it hard to use.

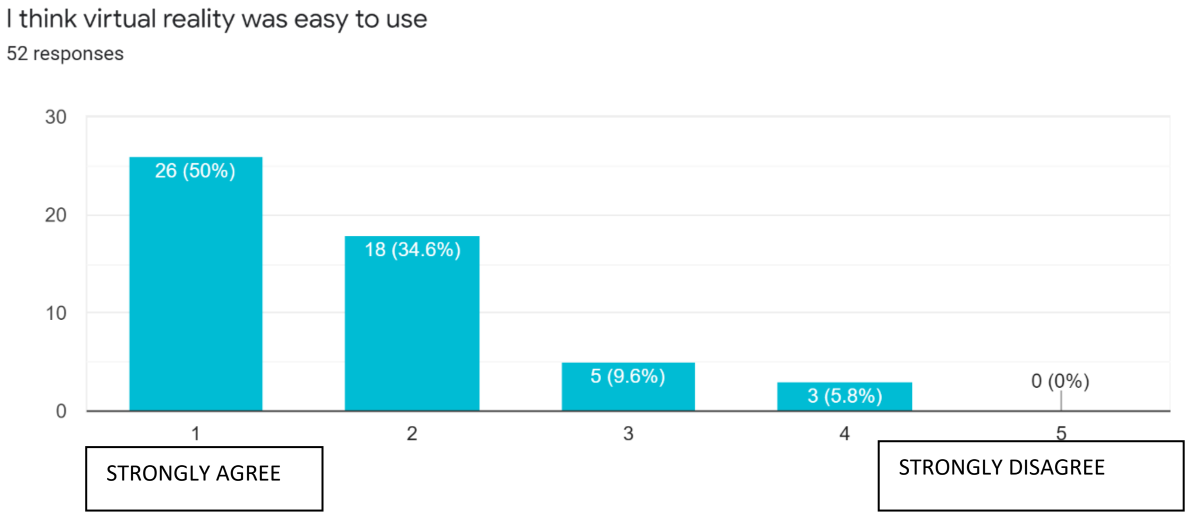


Figure 8.12: Virtual reality ease of use

The respondents were then asked whether they agreed that their interaction with the virtual reality was clear and understandable (See Figure 8.13). 54.9% strongly agreed, with 27.5% agreeing, and just 2% strongly disagreeing. However, despite this, the researcher noticed that users faced some difficulties during the virtual reality experience, with some needing assistance in order to be able to teleport and navigate as well as to interact with the experience.

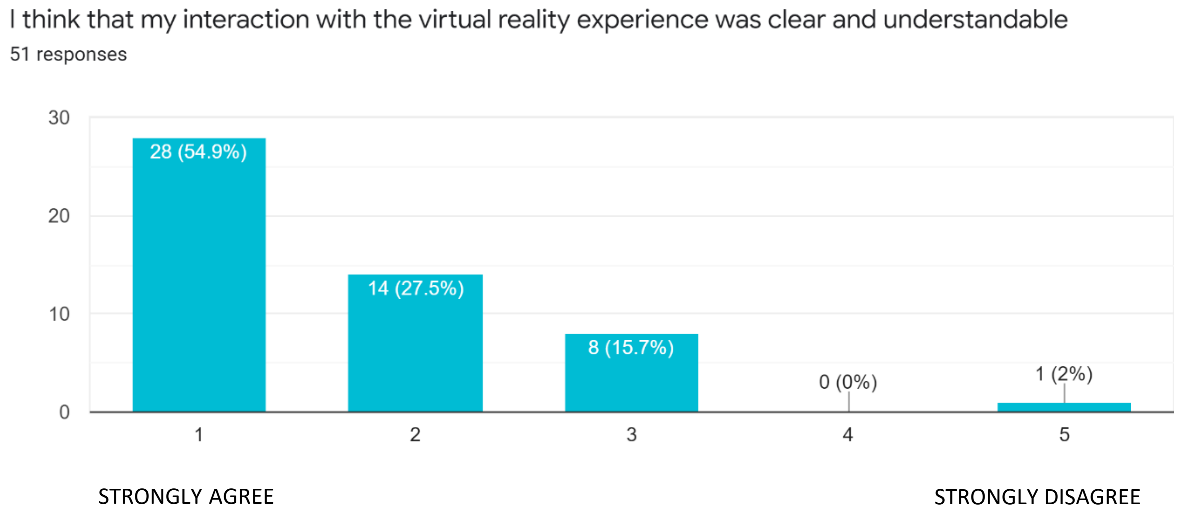


Figure 8.13: Clarity of interactions with the virtual reality experience

The next question asked whether respondents thought their skills in using virtual reality experiences would increase over time. As Figure 8.14 shows, 75% of respondents strongly agreed, with a further 17.3% agreeing. The researcher also noticed a significant improvement in the skills of the users towards the end of the experience in comparison with the beginning.

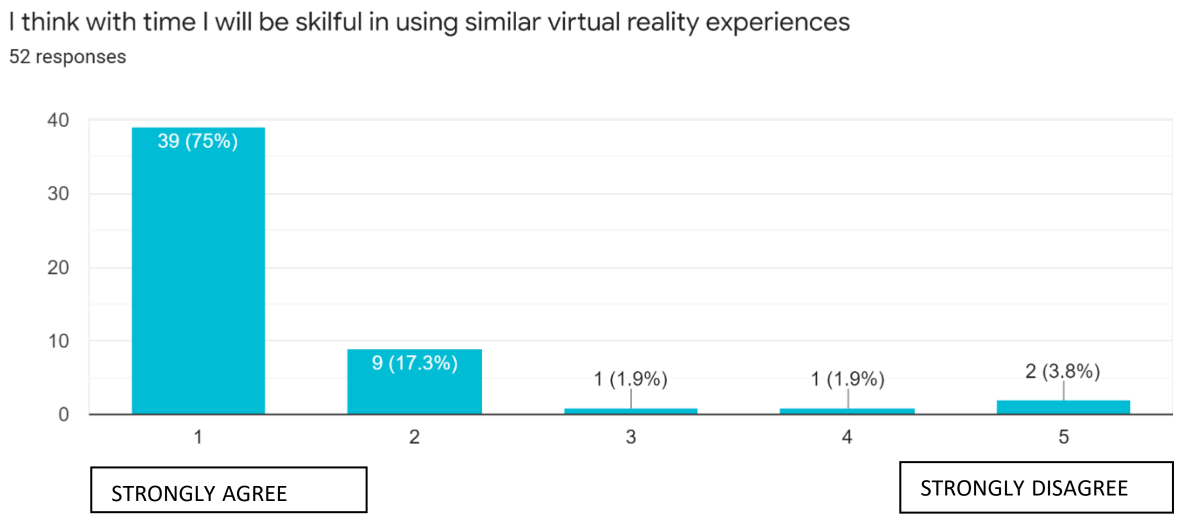


Figure 8.14: Increasing skills in using virtual reality experiences over time

Then respondents were asked if they thought they had enough knowledge about using virtual reality to be able to be informed about archaeological sites. As can be seen in Figure 8.15, responses were mixed. 40.4% of users strongly agreed that they had the required knowledge, while 26.9% agreed, and 17.3% were neutral. 7.7% disagreed and another 7.7% strongly disagreed. Although these last two percentages are not very high, they need to be taken into consideration while making decisions regarding applying virtual reality experiences at museums or archaeological sites. The researcher also observed, through comments users made and discussions with them, that they might not have enough knowledge and awareness to be able to use virtual reality without further

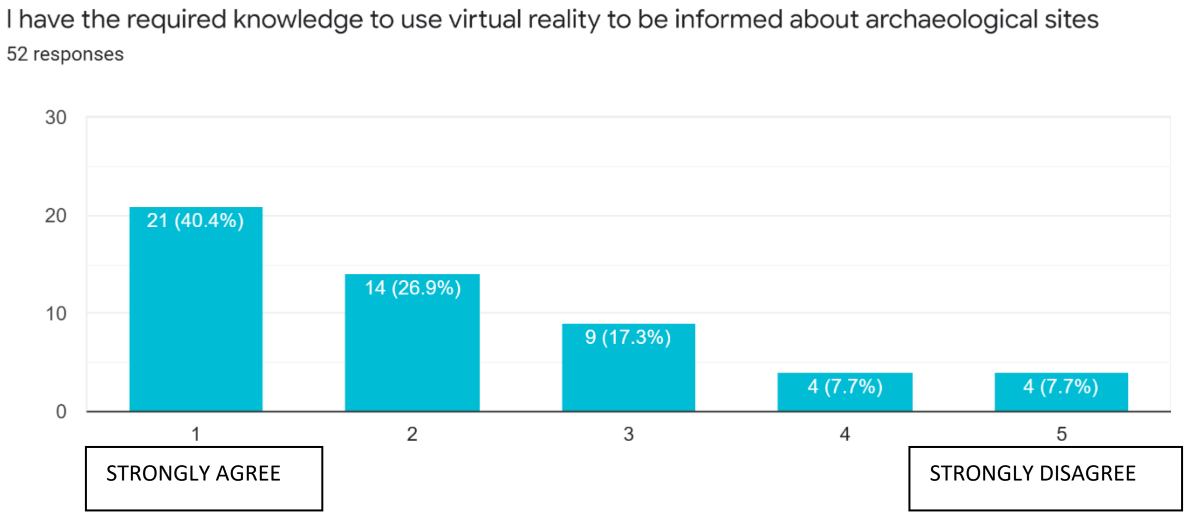


Figure 8.15: Having the knowledge required to use virtual reality

assistance.

The respondents were also asked about their familiarity with virtual reality experiences. This was done by asking them if they thought virtual reality was similar to other types of technologies they have used to access information about archaeological sites. This was important to check their familiarity and also to see if virtual reality has a different impact on the user compared with other types of technologies. The largest proportion of respondents (25%) strongly disagreed that virtual reality is similar to other types of technology; however, 23.1%, the next highest percentage, agreed. Thus, it is clear that users were divided on this point (See Figure 8.16).

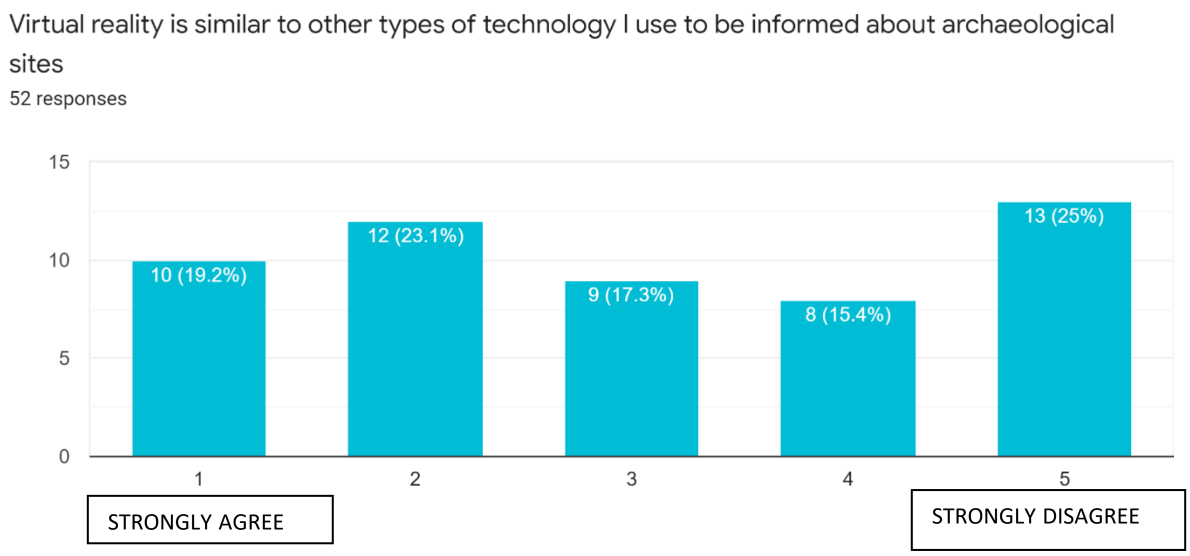


Figure 8.16: Similarity of virtual reality to other types of technologies

The respondents were also asked if they thought they would need assistance while using the virtual reality experience if they encountered difficulties. As before, respondents were divided on this question, with 30.8% agreeing they would need assistance, while 25% were neutral and 19.2% disagreed (See Figure 8.17). Give these responses, it is recommended that assistance should be provided whenever such virtual reality experiences are applied.

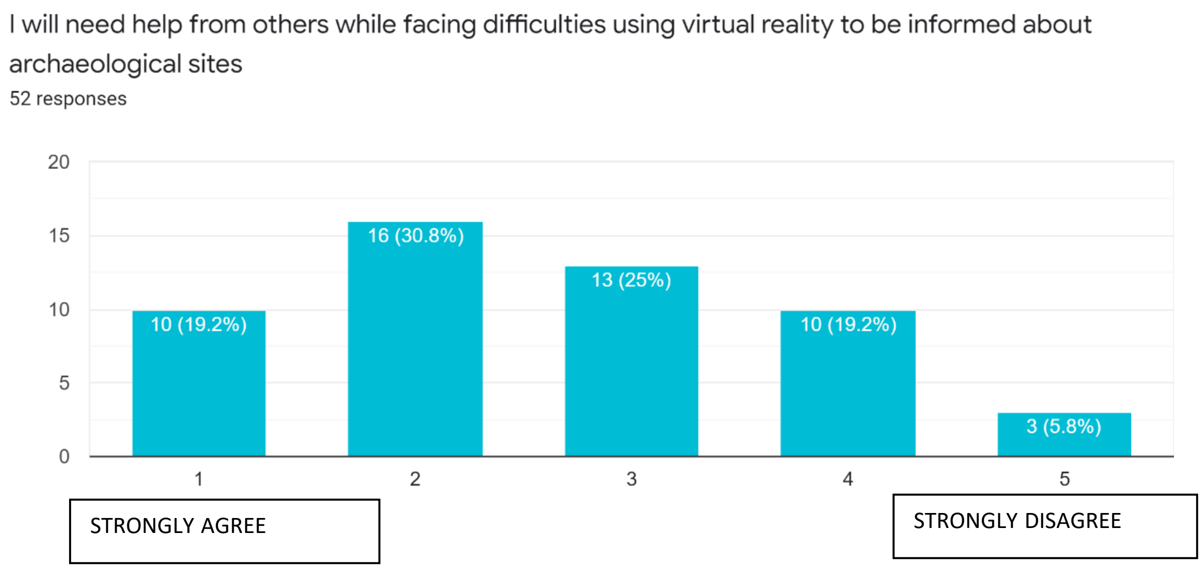


Figure 8.17: Need for help and assistance while using virtual reality experience

Other questions asked users for more specific details about the way they felt about the experience in an attempt to understand how they experienced the virtual reality. The first question asked if users felt as if they were in control of the experience. As shown in Figure 8.18, more than half of the respondents (57.7%) strongly agreed that they felt like they were controlling the virtual reality experience and a further 28.8% agreed. Only 3.8% were neutral and another 3.8% disagreed, with just 5.8% strongly disagreeing.

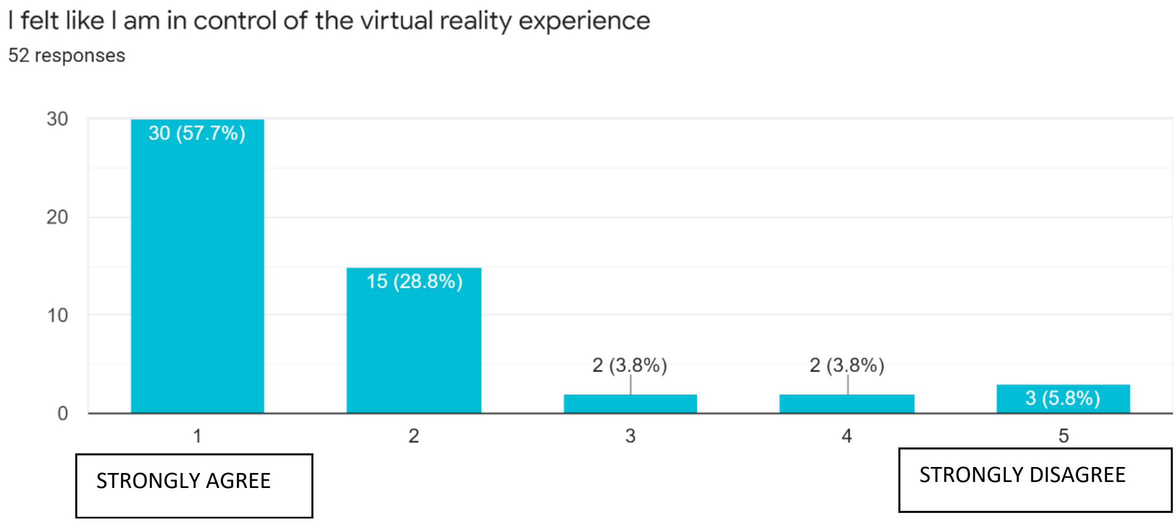


Figure 8.18: Feeling in control of the virtual reality experience

The respondents were then asked if they experienced any nervousness about using the virtual reality experience. Just under a fifth of respondents (17.6%) agreed they felt nervous during the experience, while 11.8% strongly agreed. However, a third (33.3%) strongly disagreed (See Figure 8.19). It was noticeable that some users felt a certain degree of apprehension while using the experience, which is not uncommon, especially with new users. One user refused to continue the experience after a few moments while another only spent around a minute and felt quite nervous.

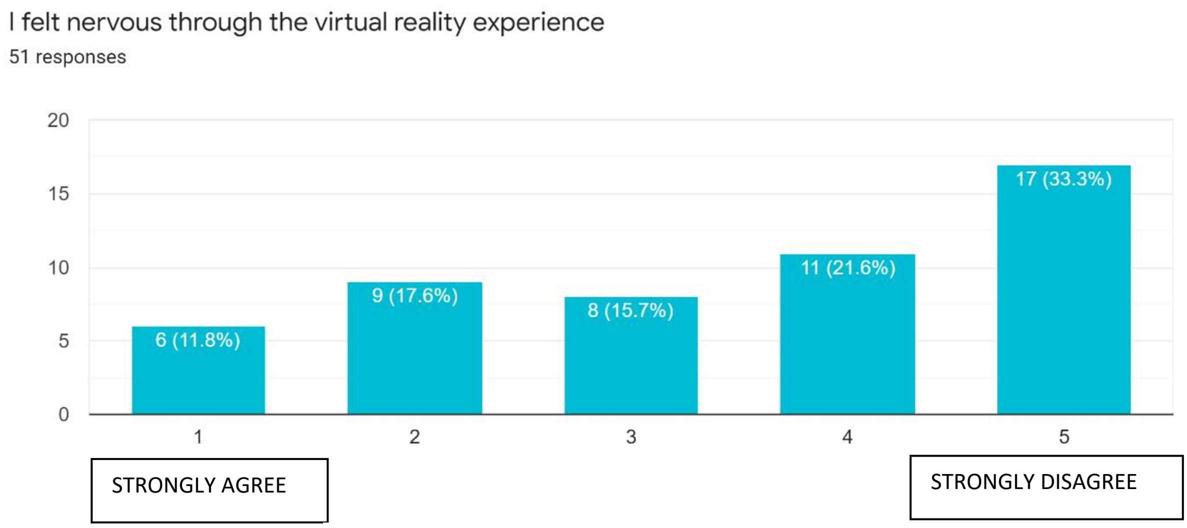


Figure 8.19: Feeling nervous during the experience

The next question asked users if they had any fears about makings mistakes they could not correct while using the virtual reality experience. 50% of respondents strongly disagreed that they felt any such fears while using the virtual reality experience. The other 50% were distributed almost evenly between those who agreed and those who disagreed (See Figure 8.20). However, in total, the larger percentage did not have a sense of being scared that they would make such mistakes.

Figure 8.20: Fear of making mistakes users couldn't correct

The respondents were then asked about whether they felt any insecurity regarding their ability to use the virtual reality experience. As shown in Figure 8.21, 44.2% strongly disagreed that they felt insecure about their ability, while 9.6% strongly agreed, a relatively small percentage.

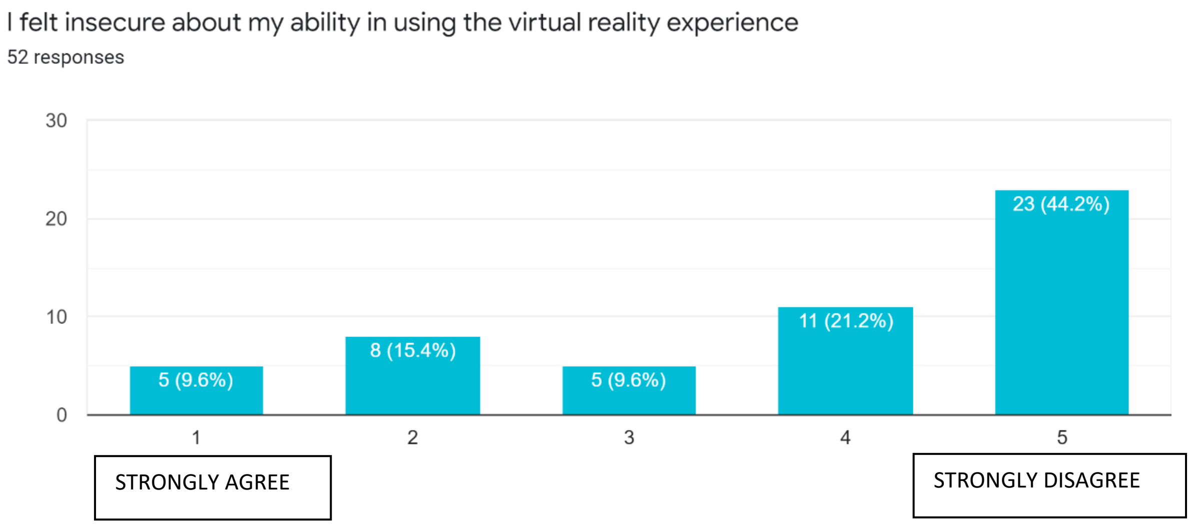


Figure 8.21: Feeling insecurity regarding ability to use the virtual reality experience

8.6.2 Evaluation of the User Interface

The next part of the survey asked users to give their opinions regarding the user interface. The user interface is the point where people interact with a computer, website, or application. The users were first asked about the visual appeal of the user interface. 61.5% strongly agreed that it was visually appealing, with a further 26.9% agreeing. Only 5.8% of users strongly disagreed that the user interface was visually appealing (See Figure 8.22).

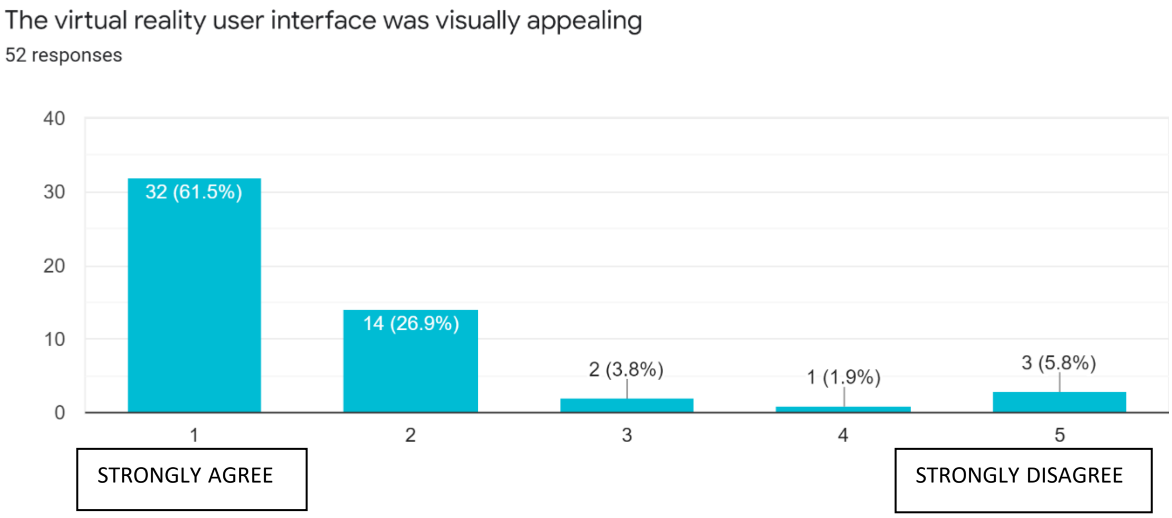


Figure 8.22: User interface was visually appealing

The following question asked whether respondents thought the interface was interactive. As can be seen in Figure 8.23, 61.5% strongly agreed that the interface was interactive, with a further 17.3% agreeing. Just 5.8% disagreed and 1.9% disagreed. Some users added suggestions for ways to develop the interface and these are discussed at the end of the survey with the feedback and recommendations. These suggestions were added at the end of the survey. The users were allowed to give their suggestions and comments which is included at the end of this chapter.

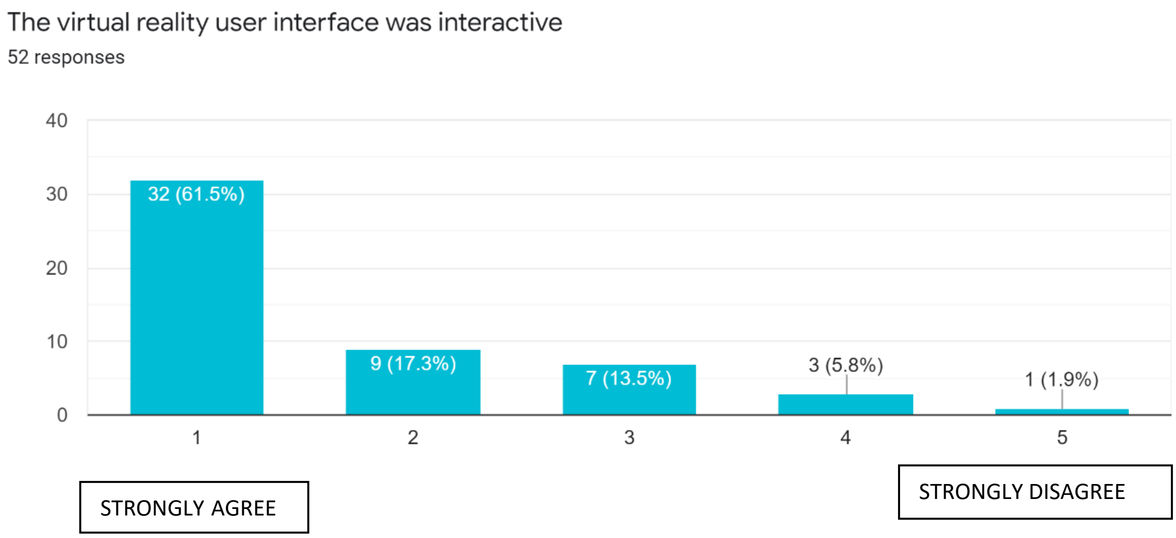


Figure 8.23: User interface was interactive

The last question regarding the user interface asked if respondents thought it was clear and easy to understand. 57.7% of users strongly agreed that the virtual reality user interface was clear and a further 25% agreed. Just 3.8% disagreed, with another 3.8% strongly disagreeing (See Figure 8.24). This means that, in general, the user interface was clear; however, some minor amendments to enhance the clarity were suggested in the users' feedback and comments that could be taken into consideration in future.

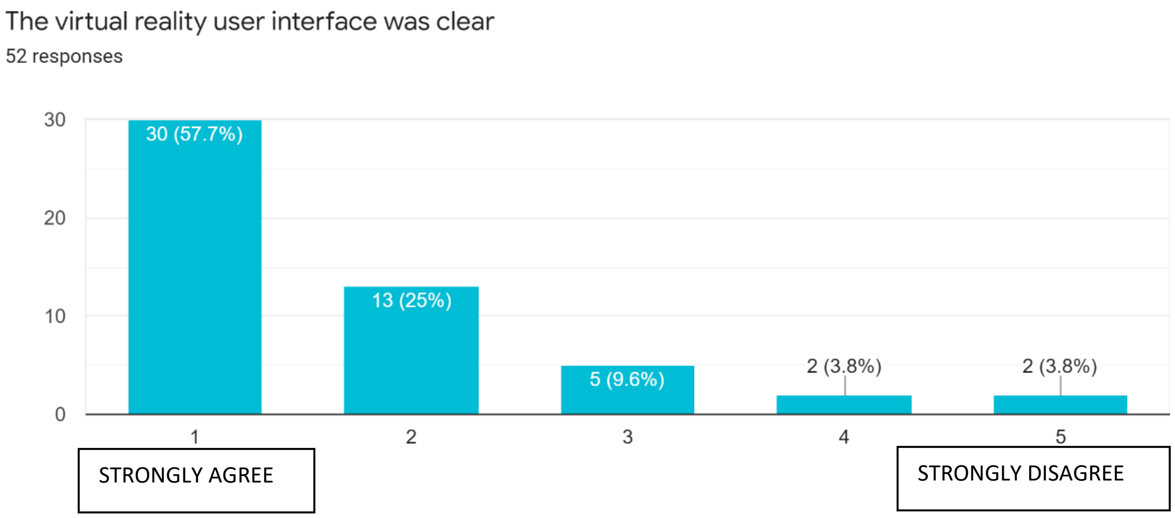


Figure 8.24: User interface was clear and easy to understand

8.6.3 Credibility, Reliability, and Trustworthiness of Virtual Reality

The following three questions explored the credibility, reliability, and trustworthiness of virtual reality and applying it to the field of archaeology. The first question asked if users thought that applying virtual reality to archaeological sites could be credible. 50% of respondents strongly agreed and 30.8% agreed, with just 3.8% strongly disagreeing and 1.9% disagreeing (See Figure 8.25).

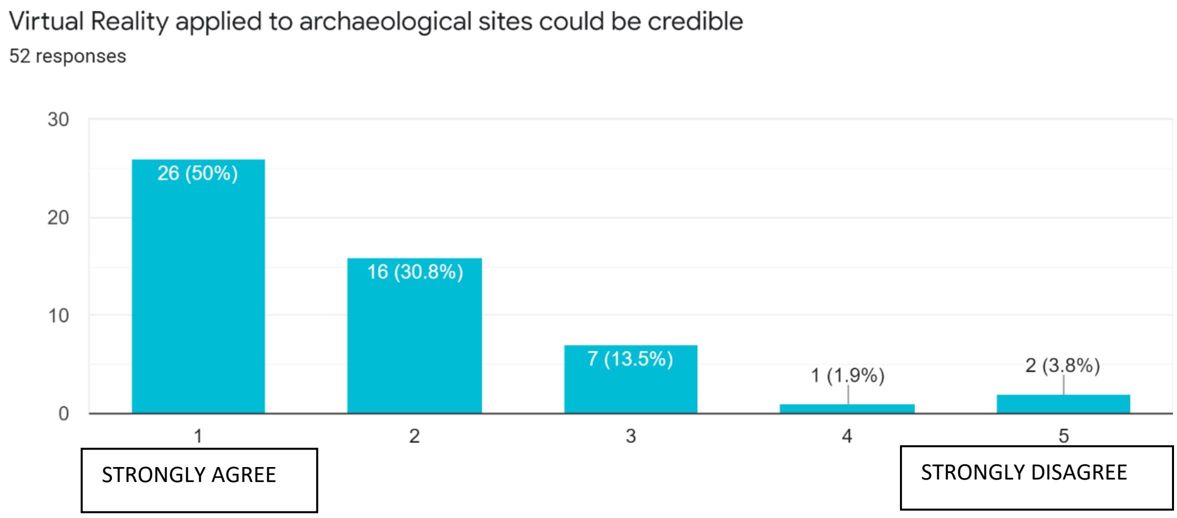


Figure 8.25: Applying virtual reality to archaeological sites could be credible

The next question asked if users thought applying virtual reality to archaeological sites could be trustworthy. As shown in Figure 8.26, the vast majority of respondents supported this idea, with 32.7% agreeing and 57.7% strongly agreeing. Just 3.8% of users strongly disagreed and 0% disagreed. This suggests that most users think virtual reality experiences are reliable and trustworthy. However, this has both a positive and negative aspect. As discussed previously, experts are often concerned with the fact that virtual reality makes reconstructions hyper-real, which creates the impression of a high degree of reliability, regardless of the accuracy of the data or reconstructions provided.

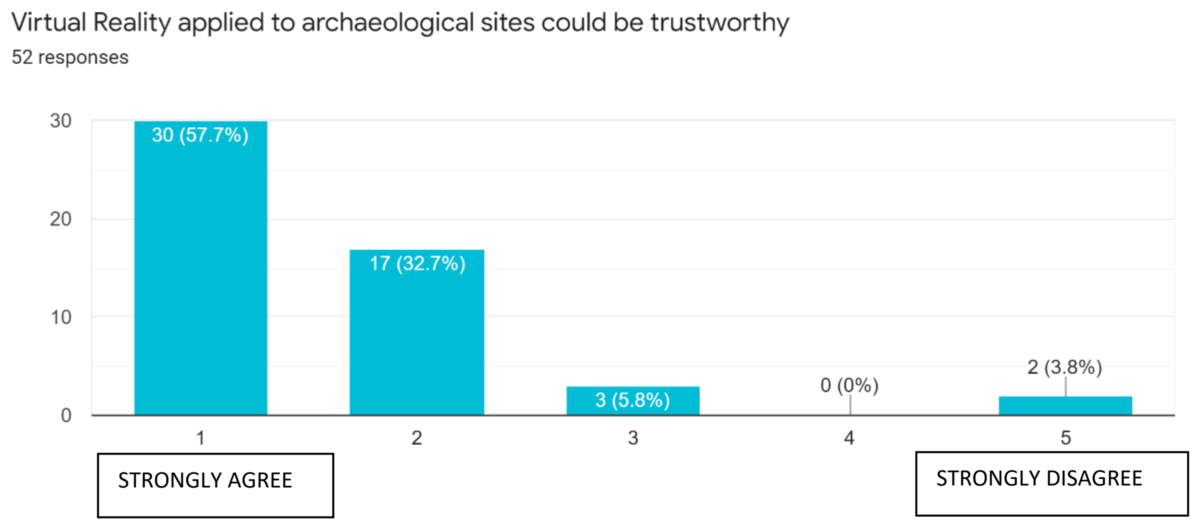


Figure 8.26: Applying virtual reality to archaeological sites could be trustworthy

The last of these questions asked if users thought that virtual reality applied to archaeological sites could be reliable. Again, 57.7% of respondents strongly agreed, with a further 30.8% agreeing. By contrast, 5.8% strongly disagreed with it being reliable and 0% disagreed (See Figure 8.27). Overall, these percentages indicate that virtual reality creates an impression of trustworthiness, which encourages users to rely on the information they see presented to them through the digital reconstructions without the need for extra references or justifications.

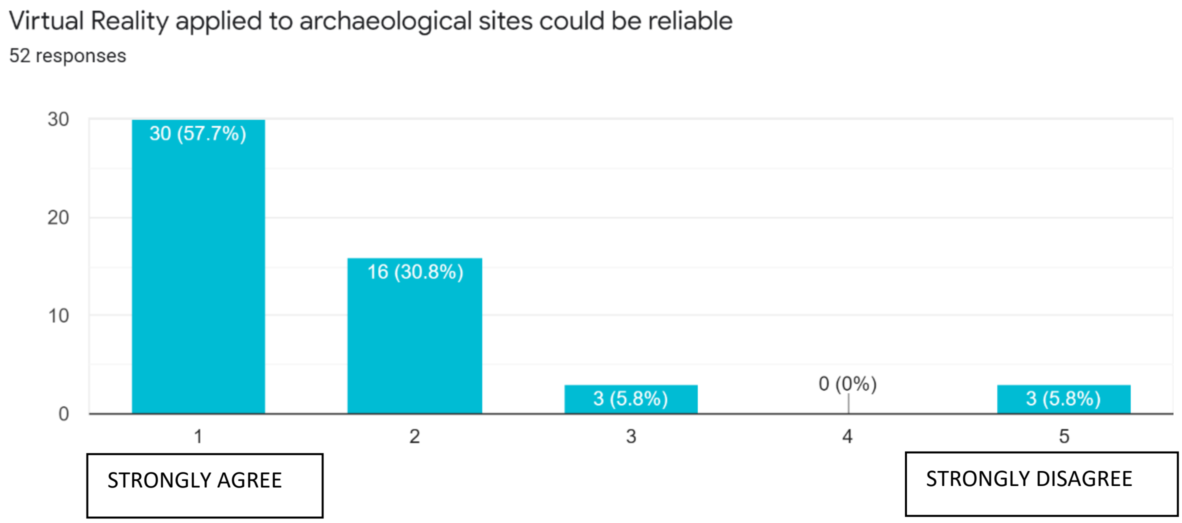


Figure 8.27: Virtual reality applied to archaeological sites could be reliable

8.7 Representing the Subjectivity of Digital Archaeological Reconstructions

The next set of questions explored the experience of the users within the virtual reality environment in more detail. These questions were aimed at assessing the methodology used for representing the subjectivity of digital archaeological reconstructions, and asked about the deployment of several different reconstructions for the same archaeological site and the use of multimedia to represent the subjective nature of the digital reconstruction of lost archaeological sites. While most questions were asked in a positively worded format, a reversed form was applied in a few questions to avoid bias. This is highly recommended when using a Likert scale evaluation (Suárez Álvarez et al. 2018).

The first two questions explored the use of several scenes within the same virtual reality experience to provide different reconstructions of the same archaeological site. As the users teleport between several reconstructions in this experience, they were asked if they thought that providing several scenes in this way was entertaining. As can be seen in Figure 8.28, almost three-quarters of respondents (71.2%) strongly agreed that providing several scenes and teleporting from one scene to another was entertaining. A further 15.4% agreed, meaning a total of 86.6% found it entertaining. Only 7.7% were neutral and a total of 5.7% disagreed or strongly disagreed (See Figure 8.28).

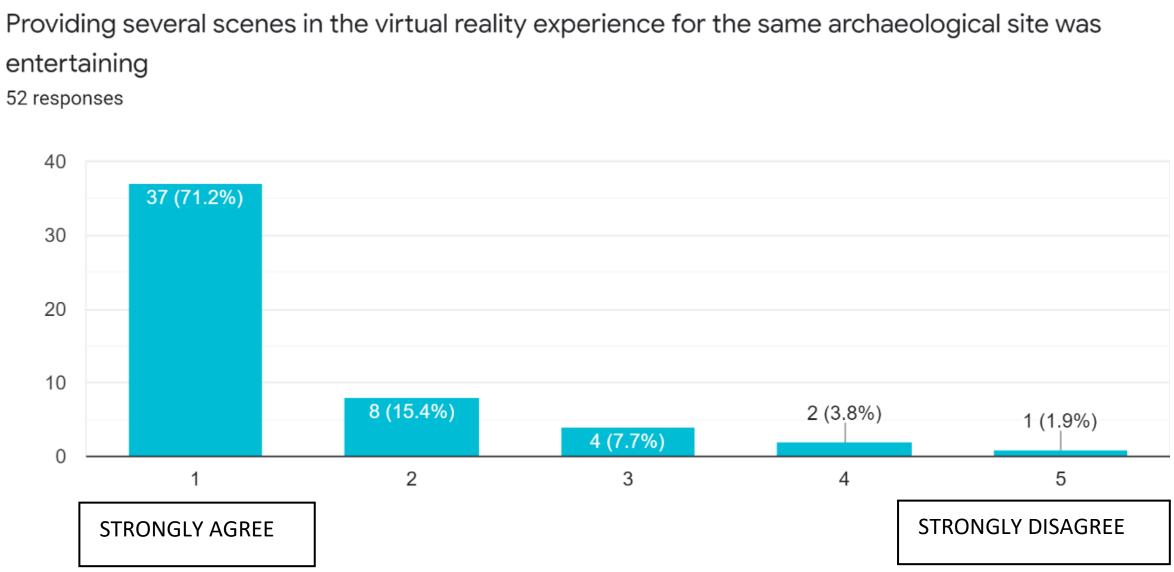


Figure 8.28: Providing several scenes within the same experience was entertaining

The users were then asked if they thought providing several scenes in the virtual reality experience was confusing. The fact that the largest proportion of users either disagreed (28.8%) or strongly disagreed (28.8%) with this idea was encouraging, and suggests that, despite multiple experts warning that providing several reconstructions for the same site might not be accepted by the public, this was not the case in this experience. However, while just 3.8% strongly agreed that the experience was confusing, 15.4% agreed and 23.1% gave an intermediate score (See Figure 8.29: Providing several scenes in the virtual reality experience was confusing). This suggests that they found this relatively confusing, something which needs to be taken into consideration. This could perhaps be done by trying to improve the clarity of the information provided or by simplifying the virtual reality experience for the user. Further research could be done to explore the best ways to improve the experience and minimize the degree of confusion faced by public users.

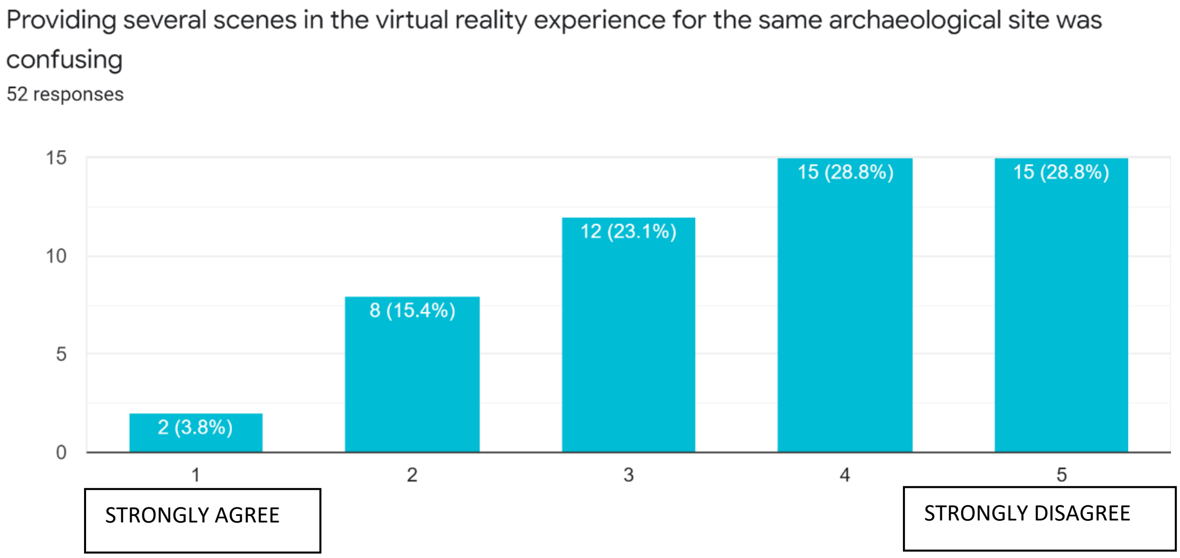


Figure 8.29: Providing several scenes in the virtual reality experience was confusing

The following two questions also aimed to explore the methodology used for representing the subjectivity of digital archaeological reconstructions. These questions focused on integrating multimedia within the virtual reality experience. The multimedia that was added to this virtual reality experience provided information about the site, its history, the digital archaeological reconstruction provided, and the person behind the reconstruction (i.e. Kircher, Lucas or Canina). The first question asked users if they thought integrating multimedia, such as text, sound and images, in this way was informative. As Figure 8.30 shows, the largest proportion of respondents (78.8%)

strongly agreed, with a further 5.8% agreeing, meaning a total of 84.6% of respondents thought that integrating multimedia in this way was informative.

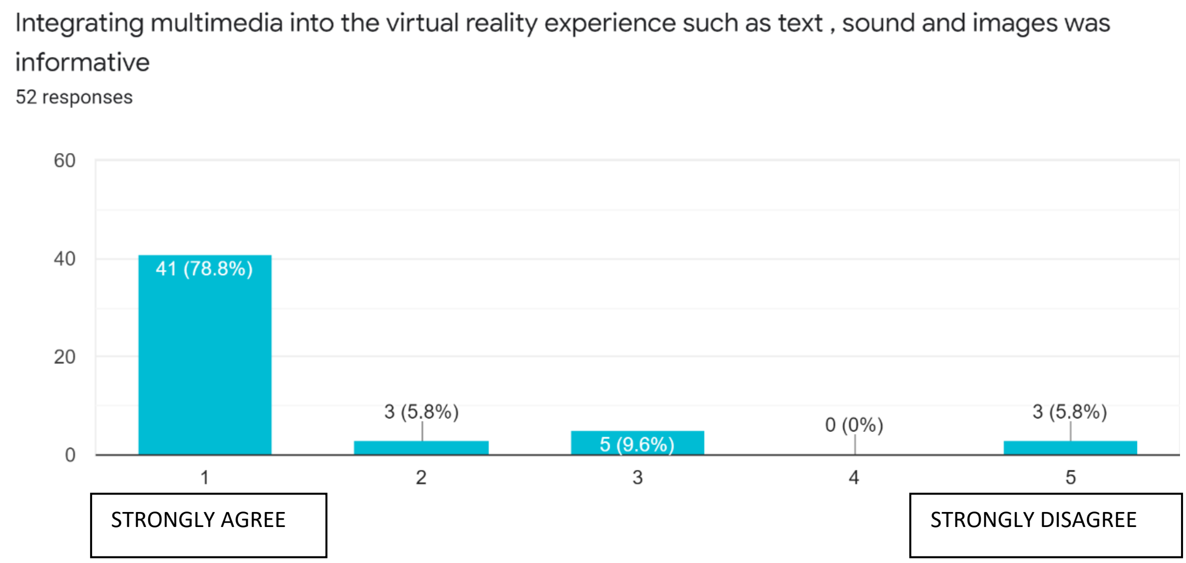


Figure 8.30: Integrating multimedia, such as text, sound and images, into the virtual reality experience was informative

The following question asked if users thought integrating text, sounds and images made the virtual reality experience complicated. Just over half of the respondents (59.6%) strongly disagreed and 15.4% disagreed; however, a combined total of 17.3% either agreed or strongly agreed (See Figure 8.31). This percentage needs to be taken into consideration and suggests that some of the multimedia elements within the experience should be simplified. Some adjustments could be made and future research comparing the simplified proposals with the more complicated versions could be done in order to create more user friendly virtual reality experiences.

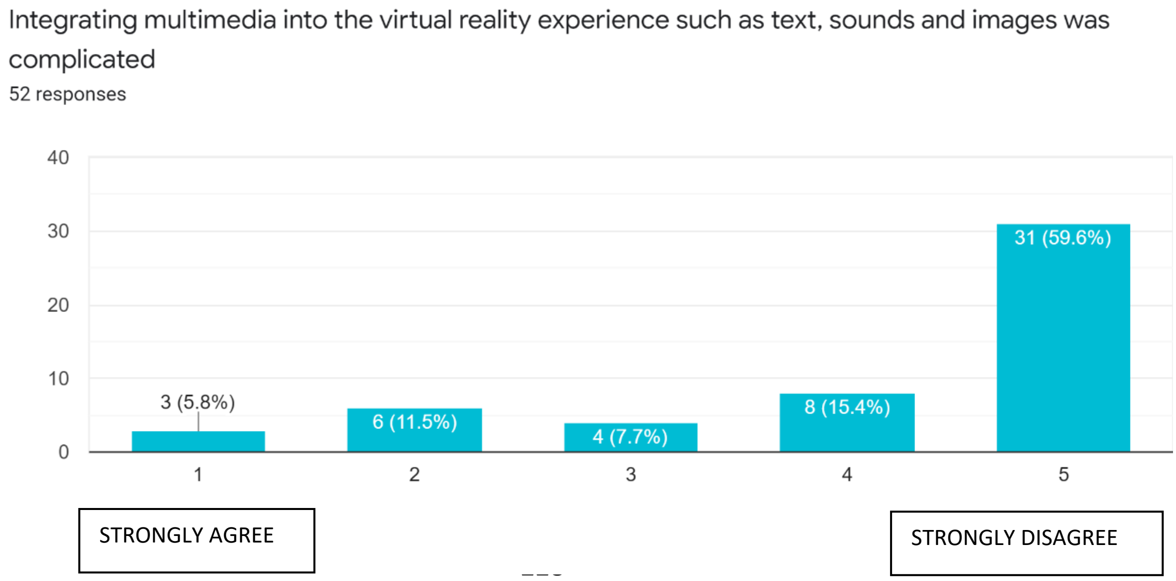


Figure 8.31: Integrating multimedia, such as text, sounds and images, was complicated

The next question addressed the subjective nature of archaeological reconstructions directly. The aim of this question was to investigate if the virtual reality experience had an impact on users' understanding that there might be several possible interpretations for the same archaeological site. Almost half of the respondents (48.1%) strongly agreed that there could be several reconstructions for the same archaeological site. This demonstrates that, despite the experts' concerns, the average user can comprehend the possibility of having different scenarios for the reconstruction of the same archaeological site. A further 30.8% of users agreed that multiple reconstructions were possible, making a total of 78.9% respondents who acknowledged the subjectivity of digital archaeological reconstructions. 13.5% were neutral regarding this question and a total of just 7.6% either disagreed or strongly disagreed, which is a very low percentage. Overall, these results suggest that presenting users with several reconstructions can be an effective way to enhance awareness of the subjectivity of digital archaeological reconstructions among the general public.

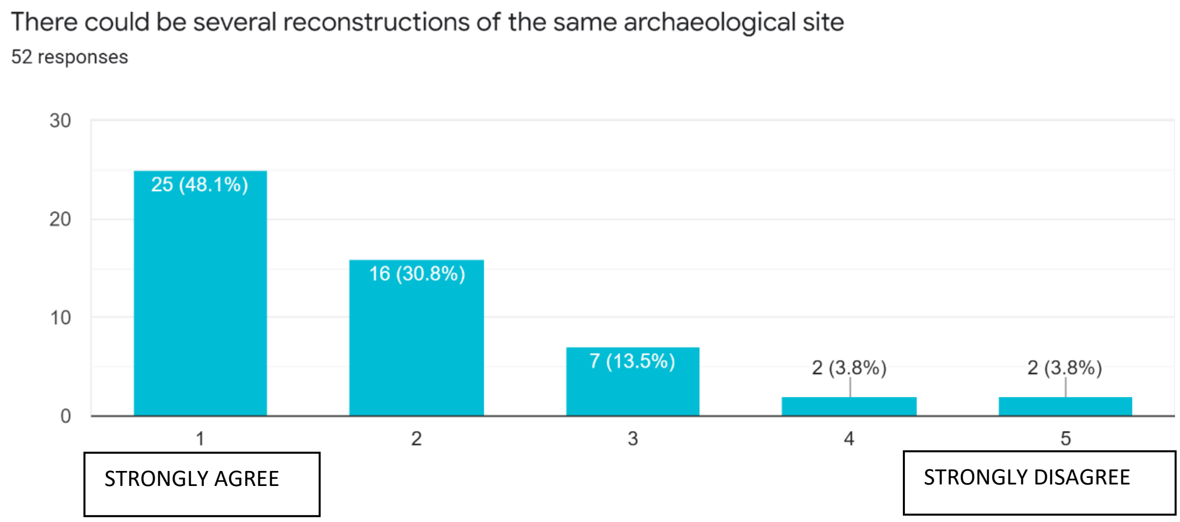


Figure 8.32: There might be several possible interpretations for the same archaeological site

The next question explored the concept of multiple reconstructions in more detail and asked if users thought using virtual reality to present different reconstructions was confusing. As Figure 8.33 shows, there was some variance in the responses to this question. A total of 65.4% of respondents either disagreed or strongly disagreed with the idea; however, just 17.3% were neutral, which means around 35% of users considered that using virtual reality to present different reconstructions was confusing to some degree.

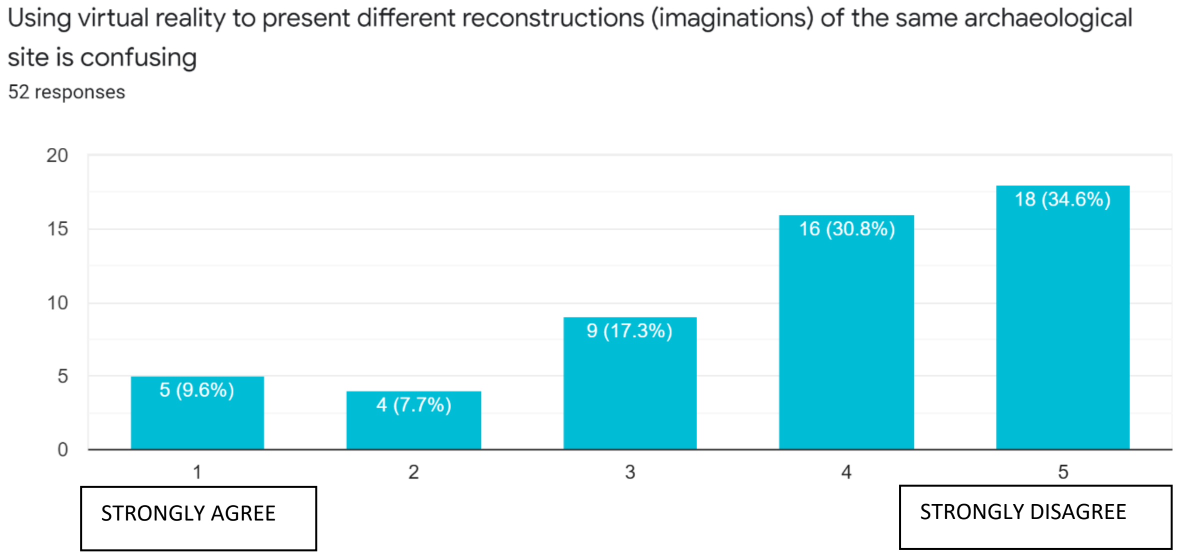


Figure 8.33: Using virtual reality to present different reconstructions of the same site was confusing

The next question asked if respondents thought virtual reality as a technology was capable of presenting different reconstructions of the same archaeological site. Just over two thirds (67.3%) strongly agreed and a further 15.4% agreed, making a total of 82.7% who thought that virtual reality could present the same archaeological site in different ways. By contrast, just 9.6% disagreed or strongly disagreed with this idea (See Figure 8.34).

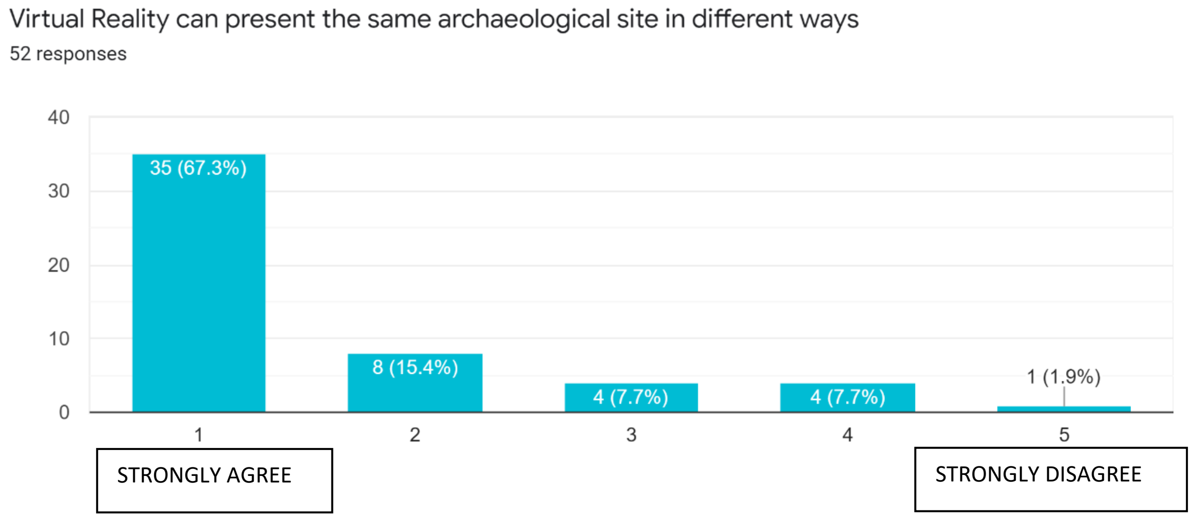


Figure 8.34: Virtual reality technology is capable of presenting different reconstructions of the same archaeological site

The following question asked if users thought that presenting different reconstructions of the same archaeological site helped them learn more about it. As Figure 8.35: Presenting different reconstructions of the same site using virtual reality helped users learn more about the site, 61.5% of the respondents strongly agreed and another 30.8% agreed. When designing the virtual reality experience, consideration was given to making it not only entertaining but also informative and educational, and these results suggest that this was successful. In this it simulates the labels in museum exhibits where one finds information about the artefacts as well as the archaeological

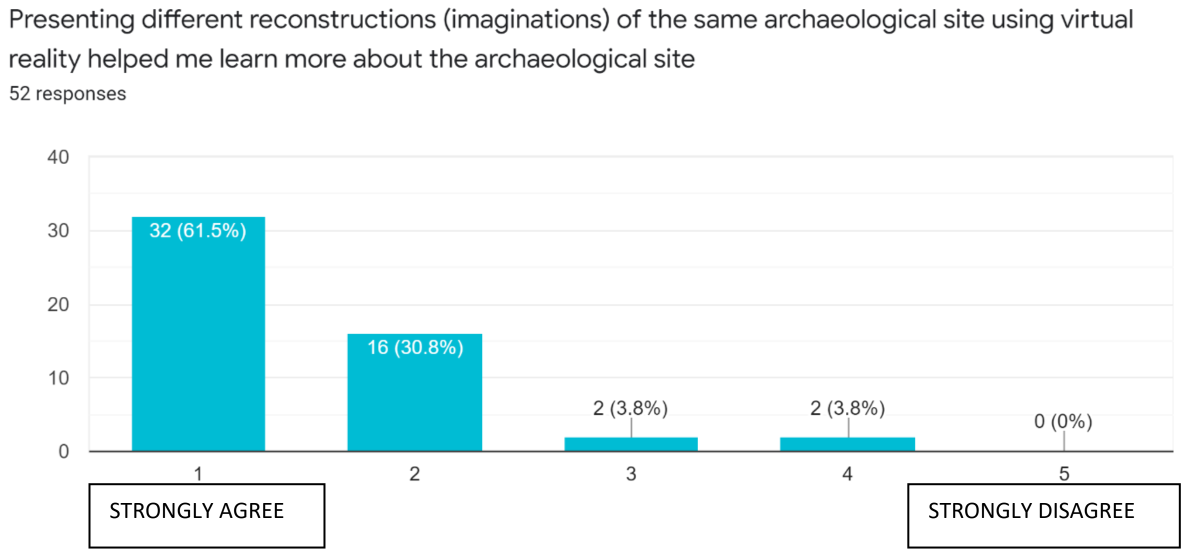


Figure 8.35: Presenting different reconstructions of the same site using virtual reality helped users learn more about the site

sites

8.8 Users' Opinion on Virtual Reality

The following questions explored users' opinions about using virtual reality in archaeological sites and museums. The questions were aimed at understanding if users would like to use virtual reality at museums and archaeological sites or not, whether they thought this would enhance their experience at those sites and if this would in return encourage them to visit the sites and would make their experience more entertaining.

The first question asked whether the users thought that virtual reality enabled them to explore archaeological sites in a way they would not be able to without it. Almost 60% (59.6%) strongly agreed, with a further 19.2% agreeing. 13.5% of respondents were neutral, with 3.8% disagreeing and another 3.8% strongly disagreeing (See Figure 8.36). After trying the virtual reality experience, some participants mentioned that they thought being able to use virtual reality to explore other archaeological sites would add a lot to their understanding of those sites.

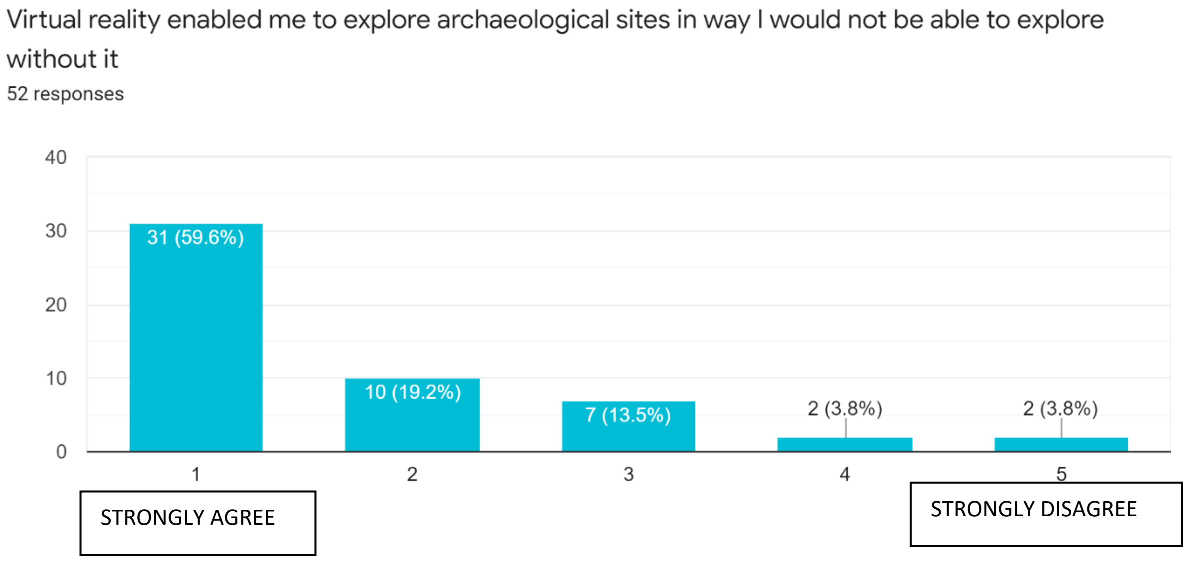


Figure 8.36: Virtual reality enabled users to explore archaeological sites in a way they would not be able to without it

The next question asked whether users thought using virtual reality in archaeological sites and museums would be fun. A very high percentage (80.8%) strongly agreed that this would be fun, with 7.7% agreeing and 5.8% neutral. Just 5.7% of respondents either disagreed or strongly disagreed (See Figure 8.37). This indicates that a large proportion of users would be in favour of using virtual reality at archaeological sites and museums as they see it as an entertaining activity.

Figure 8.37: Using virtual reality in archaeological sites and museums can be fun

The following two questions investigated whether or not users would use virtual reality in archaeological sites and museums. Two similar questions were used, each with a slightly different format, to be reassured about the users' preferences. The first question asked if users would like to use virtual reality in archaeological sites and museums. As shown in Figure 8.38, 72.8% of the respondents strongly agreed that they would, with an additional 17.6% agreeing, making a total of 90.4% respondents in favour, a very high percentage. Just 3.9% strongly disagreed and only 2% disagreed, making a total of just 5.9% who would not like to use them (See Figure 8.38). This suggests that virtual reality technology could be widely used in Egypt and within wider middle eastern contexts.

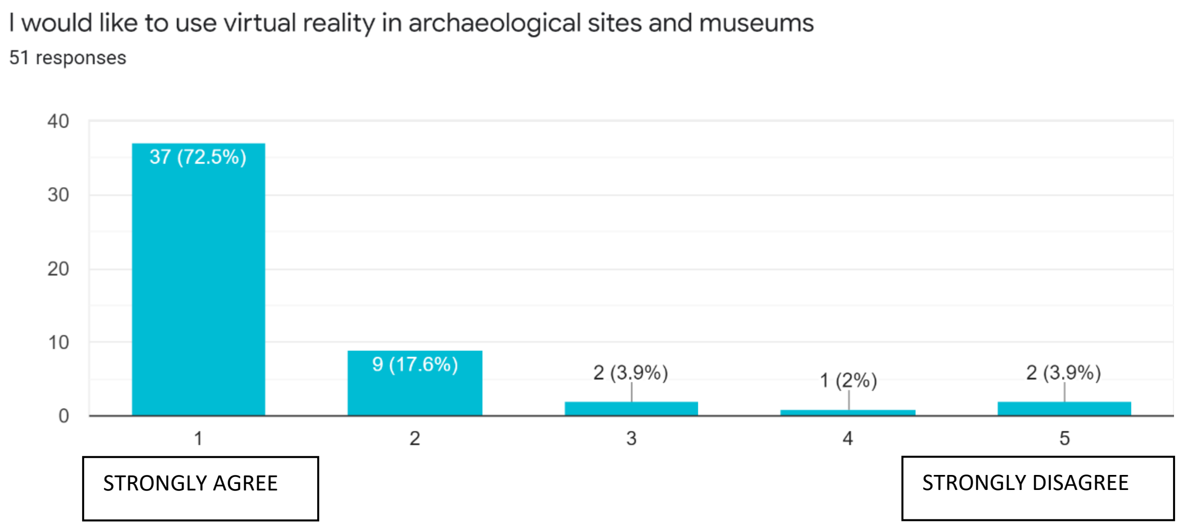


Figure 8.38: Users would like to use virtual reality in archaeological sites and museums

The second question is very similar to the past question however it was targeting whether the users' will actually use it if it will be available. There was a bit of variance within the response rate to that question in comparison with the past one. A percentage of 69.2% strongly agreed that they would actually use it in comparison to 72.% strongly agreeing that they would like it to be available. A total of 92.3% falls within the agreement category which is quite close and even higher to the percentage in the past question which was equal to 90.4%. This question generates an extra assurance that users actually prefer having virtual reality experiences at archaeological sites and museums and that they would actually use them.

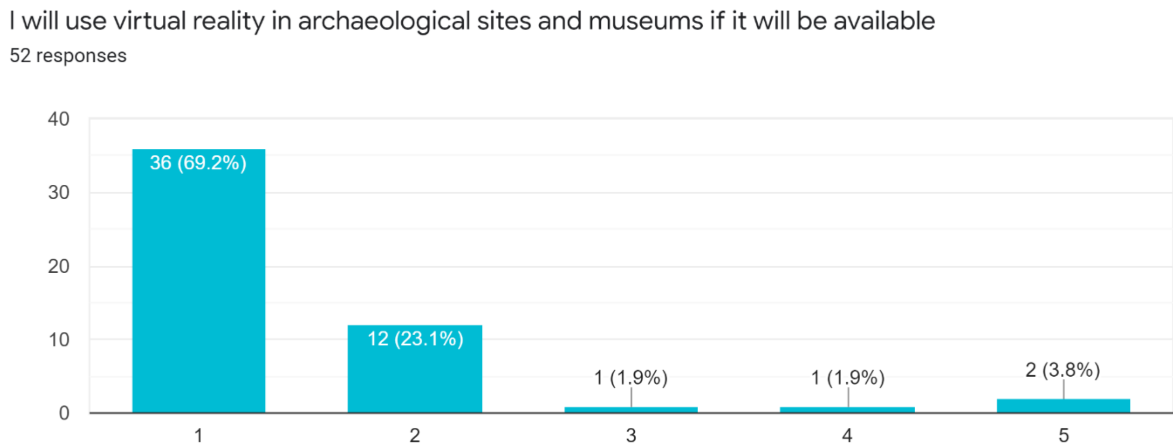


Figure 8.39: Respondents would use virtual reality in archaeological sites if it was available

8.9 User's Overall Feedback:

The final section of the survey included a tab where users can add their own personal feedback. Through this tab there were some suggestions for upgrading the virtual reality system with further ideas. There were also suggestions making virtual reality available to the public by using it for tours in Egypt. There were some positive feedback comments that the experience was enjoyable and that the choice for sound effects and narration was good. Users also clarified that they enjoyed experiencing the building from different angles such as viewing it from the top. Users also commented that this could attract the youth and kids to know more about historical sites.

Some comments for improvement included having a better resolution which could be achieved using more advanced headsets. Also a user suggested that there could be a user manual before using the experience to explain how to navigate through it and how to click on different narrations and sound effects. Also another user commented on the resolution of the text that it was not clear enough. All the issues with the resolution were due to the use Oculus Go as a headset as it has limited resolution. Oculus go was chosen due to the availability as previously mentioned in other chapters. Another comment on quality was that the experience needed better graphics. All those comments are quite important to be taken into consideration in the development of future experiences. The following is the feedback of the users that was written by them at the end of the survey. The survey feedback was anonymous so the users here are given numbers to identify them.

<u>The users' comments as extracted from the survey:</u>

1. User 1 : "It will be much better if you upgraded with more ideas"
2. User 2: "It would be interesting to have VR for historical and natural tours in Egypt"
3. User 3: "I've enjoyed this experience alot as it was my first time to use vr, looking forward to try it in new places"
4. User 4 :"The experiece was great overall I really enjoyed it. It was fun to see the different versions of the same site and to explore each one of them."
5. User 5:"I wish the resolution is higher with support for high refresh rates"
6. User 6: "User manual at the beginning. Clearer text."
7. User 7: "Better graphics. Easier motion. But in general great work."
8. User 8 : "Good choice of sounds effect and narration."
9. User 9: "Was tremendously awesome experience Farida 👏"
10. User 10 :"A super cool experience. I believe that adding subtitles would enhance it."
11. User 11:"Best experience through VR is the view of architectures from different angles and wide view scopes, enjoyed most views from the top which would be hard to experience if in person."
12. User 12: "Using Virtual Reality in Interior Design will be great"
13. User 13:" I liked it so much"
14. User 14:"I really enjoyed it. It was so real and fabulous"
15. User 15:Was an enjoyable experience
16. User 16:It was a wonderful experience
17. User 17: "The experience was really good. I would like to try it again numerous times"
18. User 18:"Beautiful"

19. User 19:"It was a very enjoyable and beneficial experience. I liked knowing more about the landmarks and monuments of my country through virtual reality as if it was real."
20. User 20:"I would like to thank the researcher who did this work for the effort and for creating such an amazing work. I believe it could attract youth and kids to love monuments through using virtual reality."
21. User 21:"Better to have a voice over to direct user for better orientation. 3D could be more clear with better resolution. More voice-overs to be integrated in the model."

8.10 Conclusion:

This chapter covered the survey that was done in order to collect the users's feedback on the virtual reality experience. It was found that during testing the experience with users there was a huge acceptance and interest in using virtual reality technologies even for first time users. During testing the experience only two users rejected completing the experience once they put on the headset. This feedback was not collected as the users refused to fill the form. All other users were interested to explore the different models and were asking a lot of questions regarding the experience before during and after. It was clear from the feedback that users would be willing to use such experiences in museums and archaeological sites. There was a general agreement that virtual reality can be a valid tool to encourage the youth and kids to be more interested in history and historic education. Not all users made the connection between the virtual reality experience and the uncertainty of digital archaeological reconstructions. However, it was clear from the users after they went through the experience that they had many questions. The main aim from the experience was to open up space for the user to have questions and to be interested to know more. Through the previous chapters it was clear that there is generally no 100% clear answer regarding the interpretation of the digital archaeological reconstructions. Through this virtual reality experience it was clear that users can also have more space to generate their own narrative on historic sites by giving them the existing evidence and existing narrative. This creates a different level of user's engagement. It was also clear that users who have no or little experience with virtual reality can still use the technology with technical assistance and proper guidance. It will be important to consider creating a users manual which would be important to guide the users instead of having a person to assist the users at all time.

9. CHAPTER 9: DISCUSSION AND CONCLUSION

9.1 Introduction

The main aim of this research was to explore the possibility of using virtual reality to generate multi-scene virtual reconstructions of archaeological sites as a way to express the uncertainty within digital archaeological reconstructions. This was done with the aim of better understanding the narratives behind these archaeological sites and the way they are represented to the general public. As this approach has never been used before within this field of research, a key part of this study involved creating a virtual reality experience based on historical reconstructions of the Hawara Pyramid site at Fayoum in Egypt, trialling it with members of the public, and investigating its impact on them. This chapter discusses the research findings in relation to existing literature, then concludes the research by summarizing the main findings and focusing on the strengths and limitations. The last section provides insights into possible avenues for future research.

9.2 Summary of Main Research Findings

Virtual technologies allow users to explore the past interactively in 3D (Sanders, 2014), and numerous approaches have been used to integrate virtual reality technologies into the reconstruction of archaeological sites. Analysis of the state of the art in this field, conducted via the literature review in Chapter 2, identified two main types of reconstruction models which have been used in research to date:

1. Using virtual reality to propose a single reconstruction of an archaeological site while adding meta data within the virtual reality model.
2. Using virtual reality to present multiple reconstructions but without integrating meta data within the virtual reality model.

This study builds on previous research by generating a virtual reality model that includes several reconstructions, where the user can teleport from one interpretation to another using different virtual reality scenes. Each scene includes a proposed reconstruction with the meta data integrated into the model. In applying virtual technologies in this way, the study fills a gap in existing knowledge by providing a method for representing the uncertainty in digital archaeological reconstructions which is theoretically grounded but can be easily understood and enjoyed by members of the public. In order to achieve this aim, the following research questions were identified:

1. How can virtual reality act as a medium for visualizing the uncertainty of digital archaeological reconstructions?
2. What are the factors contributing to the subjectivity and uncertainty of digital archaeological reconstructions?
3. Is virtual reality a suitable medium for presenting the uncertainty of digital archaeological reconstructions to the general public?

These questions are answered below, drawing on findings from both the theoretical and applied elements of the study.

9.2.1 How can virtual reality act as a media for visualizing the uncertainty of digital archaeological reconstructions?

The literature review conducted for this study (See Chapter 2) included a detailed investigation into the current state of the art in relation to the use of virtual reality as a media for visualizing the uncertainty of digital archaeological reconstructions. Numerous visual approaches used for this purpose were identified, and these can be classified as follows:

1. Presenting an archaeological reconstruction in one model, with different degrees of uncertainty shown using the following:
    - "Coloration" schemes (colours, for example, green = confident, yellow = medium confidence, red = not confident; shades or saturation of a colour; black and white versus colour)
    - Patterns, hatches, line types
    - Materials
    - Rendering type
    - Transparency (opaque = confident, different levels of transparency for varying degrees of confidence)
2. Presenting an archaeological reconstruction in one model as a combination between a 3D survey of an existing site and 3D models for the reconstructed parts. This can be done using the following:
    - Photogrammetry survey
    - Laser scanning survey
    - 3D modelling using digital software

3. Presenting an archaeological reconstruction using virtual reality by presenting several proposed reconstructions for the same heritage site. This can be done using the following:
    - Virtual Reality software (e.g. Unity 3D, Unreal engine)
4. Integrating meta data within a reconstructed model to explain the rationale behind the reconstruction and the data used as a reference.

This question was also explored through the virtual reconstruction of the Hawara Pyramid site, which is the application of this research. In order to further understand how virtual reality can be used to represent the uncertainty of the reconstruction of archaeological sites, a novel approach was applied in the case study of the Ancient Egyptian Labyrinth of Hawara. The approach involved using Unity 3D software to create a virtual reality experience that presents multiple interpretations of the lost heritage site of the Egyptian Labyrinth. The experience includes several interpretations, with meta data explaining what evidence the reconstruction is based on. The reconstructions themselves are based on historic interpretations by different historians, archaeologists or artists, each of whom imagined the labyrinth in a different way. Representing these different interpretations together provides users with further understanding regarding the reconstruction; giving them the opportunity to explore them within a virtual experience helps to generate a sense of uncertainty regarding the reconstruction itself, underlining the multiple ways in which it has been interpreted.

9.2.2 What are the factors contributing to the subjectivity and uncertainty of digital archaeological reconstructions?

The second research question explores the factors that contribute to the subjectivity and uncertainty of digital archaeological reconstructions. Through the literature review the two main drivers for the uncertainty are classified as follows:

1. The evidence used as a base for the reconstruction: this includes all the different types of data involved in the reconstruction process.
2. The interpretation of the evidence used which is done by the expert or expert generating the reconstruction.

The sources of data and the types of evidence that contribute to the digital archaeological reconstructions were explored in order to further understand how uncertainty occurs within the reconstruction process. The types of evidence were found to be as follows:

1. Actual remains on site, including the following: architectural features, archaeological artefacts, archaeological biofacts

2. Historic data, including the following: textual evidence, visual evidence
3. Contextual data, including the following: geographic and geological context, historic context

As the interviews with the experts underlined, the interpretation of archaeological evidence is a process that generates high levels of uncertainty. The interviews proved that experts with different backgrounds and expertise, or even those with similar backgrounds, being presented with the same evidence would interpret the data differently, generating different reconstructions each time. The factors that generate this degree of uncertainty are classified as follows:

1. Expert's background (Art historian, Architect, Archaeologist, Artist, etc.)
2. Paradigm (processual, post-processual, experiential, interpretive, cognitive, phenomenologist)
3. Peer review (Number of experts)
4. Interdisciplinarity of experts
5. Personal judgement

The fact that the interpretation process is different from one expert to another was tested by examining the opinions of different experts through conducting interviews. The main aim of the interviews was to conduct an in-depth investigation into the processes by which the experts generate a digital reconstruction model. The questions investigated the types of evidence used and the methodologies used in order to identify inconsistencies between the different experts. As a result of the interviews, a hierarchy of subjectivity was generated from the least subjective type of evidence to the most subjective. The interviews also revealed that the experts used different types of evidence and ascribed different degrees of importance to them, with the types of evidence used depended on the type of project involved and the aim of the digital reconstruction model. The hierarchy that was generated based on the interviews with the experts identified survey data on site as having the lowest degree of subjectivity, with the environmental context having the highest.

9.2.3 Is virtual reality a suitable media for presenting the uncertainty of digital archaeological reconstructions to the general public?

In order to answer this question an extensive literature review was conducted, examining research that involved the application of virtual reality as a media for presenting the uncertainty of digital archaeological reconstructions. As this field of research is relatively new, not many applications have been created for this purpose and disseminated to the general public; however, previous research has demonstrated that virtual reality as a media is quite acceptable to the public, especially in museums and heritage sites. The literature review also examined the different capabilities of this technology in order to explore the endless applications that could be generated. The different technologies in this field that aid in presenting the uncertainty of digital archaeological reconstructions include the following:

1. 3D documentation technologies
2. 3D modelling software
3. Virtual reality software
4. Integrated modelling software

All of these software, used either in combination or separately, offer the possibility to present the uncertainty of digital archaeological reconstruction. The final digital models could then be presented to the public in different types of projects, which could be classified as follows:

1. Documentation
2. Representation
3. Dissemination

The types of projects that could benefit from the virtual reality technology could also be classified as follows:

1. Preservation and collection
2. Site enhancement and promotion
3. Education and learning
4. Hypotheses and evaluation

These types of projects could all be used in applications that assist with communicating cultural heritage to the general public. However, some types are more commonly used with the general public, namely dissemination projects and projects related to site enhancement and promotion, education and learning. These projects could benefit significantly from using virtual reality technologies. This is because virtual reality has an interactive nature which makes it a very suitable media for use with the general public.

However, the uncertainty of digital archaeological reconstructions is a complex idea that can be hard to be comprehended, especially for the general public. It is a concept that is usually investigated and explored only by experts, and even the state of the art focuses mostly on using virtual reality for hypotheses and evaluation or documentation and preservation, while presenting the public with just one single reconstruction.

In order to fill this gap, the last part of the research involved testing the virtual reality experience with the general public and evaluating the experience to support future enhancement and development. The aim was to explore the viability of using virtual reality as a media for presenting the uncertainty of digital archaeological reconstructions to the general public. The evaluation covered the following main sections, with several questions in each section to gather users' opinions regarding the experience. The key findings in each section are summarised below:

1. *Previous experience with or knowledge of virtual reality and archaeology*

   Only 36.5% of the participants had previous experience with virtual reality. The level of users' knowledge of archaeology was intermediate, with 36.5% classifying their knowledge as neutral on a scale of 1 to 5. As for the users' knowledge of virtual reality, it was also intermediate, with 32.7% classifying their knowledge to be neutral on a scale of 1 to 5.

2. *Using virtual reality for reconstructing archaeological sites*

   In general, the participants were of the opinion that virtual reality may increase their interest in archaeological sites, with 75% strongly agreeing. Also, 75% strongly agreed that virtual reality may help them access information about an archaeological site more quickly.

3. *Usability of virtual reality experience*

   The usability of the virtual reality experience was generally agreed to be intermediate, with most users agreeing that they could use virtual reality but with some assistance. 50% strongly agreed that virtual reality was easy to use and 0% strongly disagreed. When asked if the experience itself was clear and understandable, 54.9% of respondents strongly agreed that it was, and only 1% strongly disagreed. Although only 40.4% of users strongly agreed that they had sufficient knowledge to use virtual reality to be informed about archaeological sites, 75% strongly agreed that their skills would develop with time.

   Users were divided on whether they would need assistance when facing difficulties using the virtual reality experience, with 30.8% agreeing and 19.2% disagreeing. This indicates that, although not all users will need assistance, it will be better to provide assistance in order to create a more inclusive experience. Users were also asked about fear of making mistakes, or nervousness and insecurity when using the virtual reality experience, and 57.7% strongly agreed that they felt in control of the experience. However, 11.8% strongly agreed that they were nervous while using the experience and another 11.5% felt they were afraid to use virtual reality. Just 9.6% felt insecure about their ability to use the virtual reality experience.

4. User's interface evaluation:

Users generally agreed that the user interface was visually appealing, interactive, and clear. 61.5% strongly agreed that it was visually appealing and interactive, and 57.7% strongly agreed that it was clear.

5. Virtual reality's reliability and credibility

This topic was approached using three different terminologies. The users agreed that they thought virtual reality is reliable and trustworthy. An intermediate percentage of 50% of the users strongly agreed that virtual reality could be credible while 57.7% strongly agreed that it could be reliable and trustworthy.

6. Representing the subjectivity of digital archaeological reconstructions:

The users were asked their opinion of using virtual reality to represent the subjectivity of digital archaeological reconstructions. A high proportion (71.1%) strongly agreed that using virtual reality to provide several reconstructions of the same site was entertaining. However, respondents did not agree on whether providing several scenes for the reconstruction was confusing. While 28.8% strongly disagreed and 3.8% strongly agreed, 23.1% were neutral.

A high percentage (78.8%) of respondents strongly agreed that integrating multimedia, such as sound, text and images, was informative, with just 5.8% strongly agreeing that integrating multimedia made the experience complicated. In terms of its effect on users' understanding that there could be several possible reconstructions for the same site, the experience had a positive impact, with 48.1% of users strongly agreeing that this was possible. When asked if virtual reality can present the same archaeological site in different ways, 67.3% strongly agreed, with just 9.6% strongly agreeing that using virtual reality in this way was confusing.

7. User's opinion on virtual reality

It was important to take a general opinion at the end of the survey about whether users enjoyed the experience and if they would use virtual reality if it was displayed in museums. 59.6% of users strongly agreed that using virtual reality would enable them to explore archaeological sites in a way they would not be possible without it, and 80.8% strongly agreed that using virtual reality in archaeological sites and museums could be fun. Finally, when asked if they would like to use virtual reality in archaeological sites and museums, 72.5% strongly agreed.

It is clear from the previous section that in order to explore the three research questions several research methods were used. It was important to explore the research questions through a literature review by looking into applied research work from various sources. In addition to exploring the literature, in-depth interviews were conducted with various experts to understand their individual methodologies and how they impact the uncertainty of digital archaeological reconstructions. The interviews revealed that the experts were inconsistent in their methodologies as the types of evidence used change from one project to another. It was also found that the mode of presenting the digital archaeological model differs depending upon the main aim of the project and the target user either experts or general public.

9.3 Discussion in Relation to Existing Literature

This research was built upon existing literature on using virtual reality in the field of digital reconstructions. This section explains how the novel approach of using virtual reality in digital archaeological reconstructions developed for this study adds to the existing body of knowledge as discussed in Chapters Two and Three.

9.3.1 Discussion in relation to digital archaeology

As discussed throughout Chapter Two, digital archaeology overlaps with other archaeological schools, notably processual and post-processual archaeology. Despite this overlap, there has been some criticism and debate regarding the influence that digital archaeology has on reducing the meanings of archaeological remains. Theorists such as Ian Hodder have expressed significant concern regarding the impact of digitization as it is often built on incomplete information (Hodder, 1992). It is this apparent limitation of digital technologies in dealing with archaeology which this research has addressed. Although it can be agreed that digital technologies offer only a fraction or section of the actual remains, they also offer the possibility of actually combining data from various resources in one domain. In that sense, they create a different dimension for the completeness of data, rather than having the actual archaeological remains separate from other data and evidence. Adding data from various sources, such as historic data, textual, and visual evidence in one platform can give us further information on the site.

Digital archaeology is obviously an advancement in the technologies that are used in the field of archaeology. It is strongly driven by new technologies which led to an understanding that it might not stand as a theoretical school (Daly and Evans, 2006). Zubrow explains in his research that digital technology as an epoch reduces the importance of digital archaeology, making it just another step in the technological advancement. However, he proposes that digital archaeology could be better understood as a mythos. It carries much more depth to it and could be much more meaningful (Zubrow, 2006). This research has explored digital archaeology as a mythos rather than discussing it as an epoch. This means exploring the meaning behind communicating heritage through digital technologies to the users, and this is seen through using digital technologies to create new worlds. This was done through the theoretical element of this study as well as by creating a virtual reality experience for the lost Labyrinth of Hawara.

One of the most important challenges of digital archaeology is the complexity of the data. This complexity arises from the variability of sources and how they are integrated in digital platforms (Daly and Evans, 2006). Through the applied part of this research, a decent amount of evidence was found regarding the ancient Egyptian labyrinth at Hawara. The approach that was used to develop the virtual reality experience aimed to present this evidence to users in an organized way in order to ensure they could comprehend the site and the evidence in a simple, accessible way. In adopting this approach, the research addressed one aspect of the challenge regarding the complexity of the data. However not all of the evidence that existed for the site was used. In order to minimize the complexity, some archaeological evidence found for the site was not used within the experience. This is, however, a limitation that could be minimized through future research.

9.3.2 Discussion in relation to virtual archaeology

Virtual archaeology is a novel field of research that pushes archaeology to new limits and adds a lot to the conventional approaches used in the conservation, documentation and dissemination of archaeology and cultural heritage (Reilly, 1991). The Seville Charter defines virtual archaeology as a scientific discipline that aims to research and develop new methods of using computer based visualizations in the field of cultural heritage and archaeology (Seville Principles, 2011). This research aimed to utilize this technology and further explore its capabilities, thereby advancing this novel field of research. This was done by developing a novel approach which could be replicated within other projects. The same methodology that was used for developing the virtual reality experience of the lost Ancient Egyptian Labyrinth of Hawara could be used with other archaeological sites that have conflicting evidence which suggests different scenarios for the reconstruction.

The literature review explored multiple technologies that are being used in the field of virtual archaeology, including those for digitization and visualization (acquisition, capturing and modelling), such as surveying existing remains through laser scanning and photogrammetry. Other technologies that were explored are geospatial, such as 3D cultural web, GIS, and historic BIM for virtual reality (VR) and augmented reality (AR). Technologies that simulate virtual presence, such as VR and AR, were also explored within the literature review, in addition to integrated modelling and virtual reconstructions. Examples of projects involving virtual archaeology were also examined in order to select the most appropriate technologies to achieve the aims of this project. As a result, this research work is based on the following technologies:

- Digitization and Visualization (Photogrammetry, 3D modelling using Sketchup)
- Geospatial (No geospatial software were used within this research work)
- Presence (Virtual reality gaming software is used [Unity])

The selection of these software was based on availability and the aim of the project. While multiple 3D modelling software exist, the choice was made to use Sketchup due to its ease of access and the need to develop the 3D models quickly. In research projects with longer time frames, other types of software could be explored in order to determine their pros and cons. However, that was not an aim of this research; thus, only one methodology was applied and specific software and technologies were chosen accordingly.

9.3.3 Discussion in relation to the London charter and Seville principles

The principles and guidelines provided within the London charter and Seville principles should optimally be all applied within any cultural heritage related project as clearly explained in chapter 3 section 3.6. The London charter mainly focused on making 3D visual research outcomes transparent. This has been achieved through developing the virtual reality experience and providing an evidence-based approach in presenting the historic evidence used in the three different reconstructions of the Labyrinth of Hawara. With each model images for the historical references were embedded in the virtual reality experience to provide the highest degree of transparency for users. As for the Seville principles this research addresses principle 4 which focuses on the authenticity of computer-based visualizations. The virtual reality experience developed clarifies for the user that the reconstructions were based on visualizations done by historians rather than being based on actual archaeological remains from the site. The research therefore adds an important dimension to those principles and charters as it presents a novel application for those principles which could be taken as a benchmark for future similar computer-based visualizations.

9.3.4 Discussion in relation to the uncertainty of digital reconstructions

Archaeology as a science is strongly affected by uncertainty. This was established through the literature review and further explored in the process of attempting to reconstruct the Egyptian Labyrinth of Hawara. In collecting the various types of evidence relevant to the archaeological site, considerable conflicts in the evidence were identified, especially in relation to the different historians, who all visualized the labyrinth differently. By exploring the basis for their reconstructions, it was found that they were based on unreliable evidence. Many of the reconstruction attempts were based on personal opinion rather than evidence, with some historians basing their interpretation on the written text by Herodotus. As a result, this research aimed to explore ways to represent this uncertainty by using virtual reality technologies. The state of the art in this field includes several approaches for presenting the uncertainty of digital archaeological reconstructions; however, virtual reality is a relatively new technology and has not been widely used to represent uncertainty in this way. Thus, this research has presented a novel approach that aims to push the limits of virtual archaeology as a science.

In order to develop this approach, a theoretical classification of the different types of uncertainty was explored and then applied to the field of virtual archaeology. The two main types of uncertainty explored were subjective uncertainty and objective uncertainty, but the research focused on the subjective uncertainty which arises from the interpretation of archaeological evidence by experts. The interviews with the experts in Chapter Five demonstrated how subjective uncertainty develops and how each of the experts have a different approaches in interpreting evidence. The aim of those interviews was to validate the findings from the literature review which were then applied in the reconstruction of the Egyptian Labyrinth of Hawara.

The research demonstrates multiple methodologies for visualizing the uncertainty of digital archaeological reconstructions. These were presented in the literature review and the novel approach that was applied to the Hawara labyrinth and pyramid site. Through those methodologies, the research proves that there are different ways to visualize uncertainty; although it is a non-materialistic quality, it can be visualized through material qualities, such as transparency, colours, textures and integrated multimedia.

The survey that was conducted with users in order to evaluate the virtual reality experience showed that the general public is able to comprehend the uncertainty of digital reconstructions when it is visualized in this way. The users' experiences also showed that the general public can handle such complex data and can use virtual reality easily. Although the interviews with the experts showed they had concerns about presenting the uncertainty of digital archaeological reconstructions to the general public, this study demonstrates that uncertainty can be presented to the public if the virtual reality experience is user friendly and presents a narration about the site that is easy to follow.

9.4 Theoretical Implications

This research work provides new insights on the uncertainty of digital archaeological reconstructions. It also creates a new theoretical framework for the uncertainty of digital archaeological reconstructions. No previous research has included a full explanation of the uncertainty of digital archaeological reconstructions and how it arises; however, this study develops a detailed understanding of both subjective and objective uncertainty and applies it to the field of virtual archaeology, which is a novel approach. The research also linked objective uncertainty to the uncertainty that results from data and subjective uncertainty to that which results from the experts' interpretations. This classification is a theoretical addition to this field of research.

9.5 Strengths of Representing Uncertainty Using Virtual Reality

Virtual reality has become an important media in the field of digital archaeology. It is being used in different applications including the documentation, representation and dissemination of cultural heritage and archaeological sites. Through the literature review and the subsequent chapters, the advantages of virtual reality as a technology in relation to the field of archaeology were explored, along with the benefits of using this technology to present the uncertainty of digital archaeological reconstructions. A number of different approaches could be applied using this technology which could help in the advancement of the field of digital archaeology, and this would benefit both the experts as well as the general public. For example, some applications could be used to assist experts in understanding the evidence and data about an archaeological site, while others could be used to provide the general public with a more interactive, entertaining and informative way to learn more about an archaeological site.

9.5.1 Immersion

Virtual reality creates a fully immersive environment which allows the user to interact with an artificial multisensory environment (See Figure 9.174). Using virtual reality as a media for representing the uncertainty of digital archaeological reconstructions creates a high degree of immersion. This media allows the user not just to see a still image of the digital reconstruction but to explore the actual spaces and navigate through the reconstructed building or set of buildings. The immersion in virtual reality environments allows a deeper understanding and a better experience. This was established by testing the virtual reality experience with the users; it was also proven through the literature review in Chapters Two and Three and the discussion with the experts in Chapter Five.

9.5.2 Interactivity

Virtual reality is an interactive media, something which was widely explored in this research to identify all the possibilities this technology has to offer. This interactivity means the user can control the environment in different ways (See Figure 9.173). It also offers unlimited creative ways for presenting the uncertainty of digital archaeological reconstructions. Integrating different types of media, including audio visual media, could clarify the evidence which was used in the reconstruction. This, in turn, contributes to minimizing the uncertainty of the digital reconstruction. Interactivity allows the user to participate in the process of information transfer which is mediated by the virtual reality devices. The user has the power to move from one space to another and to spend as much time as they wish in each space. Users can also choose when to display the multimedia information and when to pause, play or replay any of the multimedia for as long as they wish and depending on their level of understanding and interest in certain types of information.

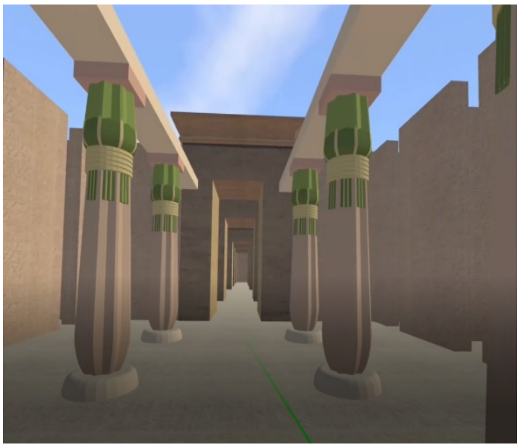


Figure 9.9.2: A Screenshot from the VR experience showing immersion

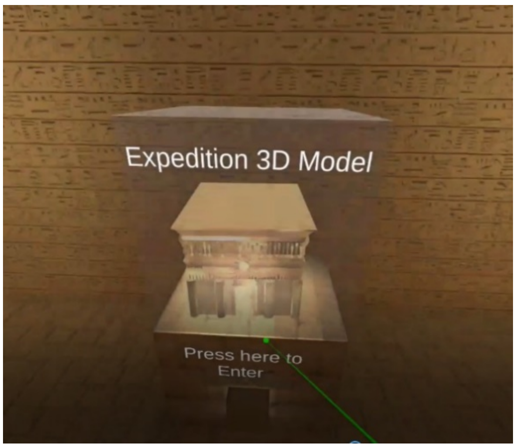


Figure 9.9.1: A screenshot from the VR experience showing interactivity

9.5.3 *Integration of various evidence and data sources*

Archaeology is a science that depends on learning more about the past through interpreting different types of evidence (Glyn Edmund Daniel, 2021). Virtual reality, as a technology, offers the possibility of combining different types of evidence and data sources in one single platform. Virtual reality can then be used in the field of digital archaeology as a platform for combining different types of evidence, such as photographs from sites, historical maps, photogrammetry models of archaeological remains, text from historic resources, and reconstructed three dimensional models. It is often difficult to interpret data related to archaeology in isolation; therefore, the integration of different types of data in one digital platform offers a better understanding of the site as well as the evidence related to it. This integration of data is very important in representing the uncertainty of digital archaeological reconstructions. Presenting multimedia within the virtual reality environment could provide users with a lot of information about the degree of certainty or uncertainty of the reconstructed models presented, something which was tested in the experience created for this study (See Figure 9.175).

Figure 9.9.3: Screenshots from the VR experience showing different types of evidence displayed on the same screen

9.5.4 *Presenting multiple interpretations*

Digital reconstructions of archaeological sites have traditionally been static, providing one single interpretation to the public. However, virtual reality makes it possible to present several interpretations within the same platform, manipulating the model to give different possible scenarios. The user can then move from one interpretation to another within the virtual reality experience. This expands users' understanding and gives them room to create their own interpretation of the site and the evidence provided. Presenting multiple interpretations can also be done through the different textures, transparencies, or colours of the three dimensional models. The possibility of presenting multiple interpretations can also assist researchers and archaeologists in research work related to a particular archaeological site. By developing virtual reality experiences that include reconstructions of several interpretations, researchers could identify gaps within evidence, enabling them to develop their research. This research study, however, focused on the user experience and how virtual reality can be used with the general public in the field of digital archaeology.

9.6 Limitations of the Research

Although virtual reality has numerous strengths, it also has several limitations; these include the complexity of using a relatively new technology. In testing the virtual reality experience with users, it was clear that they would need some degree of assistance in order to be able to fully experience the virtual reality model. A few users, especially those older in age, resisted trying the virtual reality experience, and it was clear from the sample that certain age groups, notably the 20 to 30 year olds, were generally more willing to experience such new technology. This limits the exposure of younger and older age groups, who might then resist using the experience. Other limitations are related to the time needed to develop virtual reality experiences. Virtual reality is a complex field of research, and several experts with various skills are typically required to develop a virtual reality experience. This process is complicated and include several phases in order to achieve a virtual reality experience of a sufficiently high standard that it could be disseminated to the public.

Furthermore, digital archaeology, including virtual archaeology, has a limitation as it only presents a replica of the original evidence. Digital technologies present a digital copy of archaeological evidence which reduces the meaning of the original evidence and can, in some cases, reduce the accuracy of the evidence too. This limitation affects both our understanding of the archaeological site and the presented digital reconstruction. Also, representing an existing site within a virtual reality experience with no actual experience within the site itself and no direct connection to reality is limited when compared with an actual physical experience of the site. This is where augmented reality offers added value when compared to virtual reality as the user would still have a connection to the actual site while exploring digital reconstructions and digital evidence.

In addition, virtual reality is still not as available to all users as other forms of technology. It is still restricted to certain users and is not even available in museums or archaeological sites, except in very limited settings. This is especially the case in Egypt and the broader Middle East. The development of the virtual reality experience, as well as running it, requires special skills and involves higher costs than other methods for providing digital reconstructions of archaeological sites. Introducing virtual reality into museums and archaeological sites will thus be a challenge due to financial obstacles as well as a lack of trained employees who can assist users if they face any difficulties. The need for such assistance was identified when testing the experience with the users.

Other limitations of the research are related to the difficulty of obtaining permission to develop any virtual or augmented reality experiences on site or testing them on the Hawara pyramid site. The site was accessible for gathering data; however, access in order to develop a virtual reality experience which could enhance the visitor experience at the site was not possible. Another limitation related to the case study was that there was an enormous amount of evidence and data available, but it was located at different museums. In the initial phases of the research, one of the proposed approaches was to develop an integrated model that combined the photogrammetry within the virtual reality experience; however, this was not possible as the archaeological finds are either displayed or stored in various museums worldwide.

9.7 Recommendations

Despite the limitations identified above, the high percentage of users who found the virtual reality experience developed for this study useful, engaging and informative suggests that virtual reality can play a useful role in educating users about archaeological sites and the uncertainty associated with archaeological reconstructions. As a result, the research offers the following recommendations for the use of virtual reality in this context based on both the theoretical and the practical findings:

- Using virtual reality in developing multiple interpretations of the same archaeological site;
- Using virtual reality in integrating multimedia and data that provide further information about the archaeological site and enhance the users' experience;
- Disseminating virtual reality experiences in museums and archaeological sites to better inform visitors about those sites;
- Giving users room for generating their own understanding and interpretation of archaeological evidence by using virtual reality;

- Providing users with information clarifying the uncertainty of digital archaeological reconstructions;
- Applying the methodological approach developed in this research on other archaeological sites;
- Using digital technologies and virtual reality to create a database for the evidence related to different archaeological sites

9.8 Insights for Future Research

Using virtual reality in the field of digital archaeology in general and in representing the uncertainty of digital archaeological reconstructions in particular is still a novel approach, and the technology holds a lot of potential to develop new theories, methodologies and applications. Due to the limited duration and resources of this research work, some gaps in knowledge were identified but were excluded. The most significant points that could be developed in future research are as follows:

- Transferring real time LiDAR scanning and photogrammetry surveys into virtual reality experiences

  During the development of the virtual reality experience of the Hawara Labyrinth and Pyramid site, some photogrammetry models were developed. However, due to time limitations and the difficulty accessing archaeological collections at museums, it was not possible to integrate the photogrammetry models and develop a virtual reconstruction based on them. Although some photogrammetry models of the archaeological remains of the Hawara Labyrinth were created through this research, time limitations and a lack of financial resources within this study meant it was not possible to integrate those models into the current virtual reality experience either.

- Developing augmented reality experiences to represent the uncertainty of digital archaeological reconstructions

  One of the approaches that has yet to be developed, according to the explored literature, is using augmented reality. Augmented reality could be used to represent the uncertainty of digital archaeological reconstructions as it offers the facility to overlay digital media on real imagery. This offers the possibility to create a direct connection between a proposed reconstruction and the existing remains. Exploring how augmented reality can assist with understanding the uncertainty of digital archaeological reconstructions was beyond the scope of this study, but future research could explore how augmented reality could be used to represent the uncertainty of digital archaeological reconstructions in ways that are different from virtual reality.

- Developing more interactive virtual reality experiences

  Future research should test allowing users to create their own narratives of the archaeological sites. This could be explored, for example, by allowing users to manipulate the reconstructed models by adjusting textures, objects, arrangements and artefacts. A more interactive virtual reality experience would give users more space to explore the archaeological site in a different way, which would strengthen the idea of the uncertainty of digital archaeological experiences. This area of research is currently under-explored, especially in the Middle East context, and those kind of experiences could also be further tested in the region.

- Testing the applicability of the methodologies adopted with other archaeological sites

  Research which attempts to apply the methodologies used in this study to other case studies could enhance the methodology adopted and further test the applicability of the methods used. Using different types of evidence to recreate several interpretations of an archaeological site can generate new and different challenges. The development of the virtual reality experience used in this research was hugely dependent on the types of evidence used, and the fact that several historians provided different interpretations of the same archaeological site. Applying a similar approach to another case study that did not include the same types of evidence would require adjustments to fit with the available evidence and resources.

- Testing the virtual reality experience with target users (experts in digital archaeology)

  Testing the developed virtual reality experience with experts in the field as target users rather than testing it with the general public can create a different insight into virtualizing the uncertainty of digital archaeological reconstructions. Experts as target users can give recommendations for enhancing the experience and they might as well benefit further from the experience and comprehend the concept of transparency in visualization in a different manner than the general public. Target users as experts can also be presented with more complicated virtual reality experiences including more complex data than the one presented in this research.

9.9 Conclusion:

The main aim of this doctoral research was to explore the application of advanced virtual reality to understand ancient architectural and archaeological history through the representation and reconstruction of the multiple interpretations of the Hawara pyramid site in Fayoum, Egypt In order to achieve this overall aim, six objectives were set (See chapter 1). The research has met these objectives to the extent of developing a virtual reality experience for representing the uncertainty of digital archaeological reconstruction and testing it with general users. The virtual reality experience was developed based on an extensive literature review and one to one interviews with experts in the field. Through the thesis methodology both theoretical and empirical data was collected, analyzed and developed to add data to the gap in knowledge in this field.

The first step towards achieving the research aim was to conduct an extensive literature review that covers the uncertainty of digital archaeological reconstruction and the use of virtual reality of archaeological reconstructions. From this review a theoretical framework was creating that discusses the use of virtual reality to represent the uncertainty of digital reconstruction of archaeological sites from a theoretical viewpoint. This framework was a novel approach to better understand the possibility and applications of virtual reality to achieve the project aim and was based on previous research. This framework covered the different types of uncertainty, the archaeological data used in the reconstruction process, the interpretation process and factors that affect it and the role that different data sets form in the process including input data , output data meta data and para data.

The development of theoretical framework was followed by another framework of using virtual reality in representing the uncertainty of digital archaeological reconstruction as an implementation. This methodological framework discussed the process starting with 3D modelling, 3D rendering, visualizing uncertainty and virtualizing uncertainty. Both frameworks are the theoretical contribution of the thesis to the gap in knowledge .The frameworks form both the theoretical and methodological basis which will be further ellaborated an applied in the upcoming chapters.

To validate the theoretical findings one to one interviews with experts were conducted. This was important as this field of research is relatively novel and is more based on practical implications. The interviews with the experts were essential to fill in any possible gaps in the theoretical findings. The interviews were concluded by developing a second iteration from the theoretical findings.The most important would be to consider the project type and aim as an important factor to determining the type of the model and which data to include and emphasize. It was also concluded that choosing the mode of presentation not only depends on the available data and the interpretation of the expert, it also heavily replies on the aim of the model, the type of the project and the target users.

To test the framework upon validation with experts the case study of Hawara pyramid and labyrinth site was chosen. A historical study was conducted in order to gather all available references discussing the history of the site. The data was found conflicting which formed an interesting case study to represent the uncertainty behind the Hawara pyramid and labyrinth site. To develop the virtual reality experience Sketchup, Blender, Unity and Autocad softwares were used. The approach that was used was novel as it combined using several interpretations of the same site along with multimedia explaining each interpretation and the evidence that it was based upon. The process of developing the virtual reality model proved successful in providing a possibility to present several interpretations of the same site within the same virtual reality platform with ease of navigation between different scenes. Testing the experience with users in general achieved the aim from the thesis. The users were able to navigate and experience the different interpretations and showed interest in using such experiences in museums and archaeological sites. Users however needed assistance during their experience and this should be taken into consideration when applying such approach in museums and sites.

To conclude the thesis covered the use of virtual reality to represent the uncertainty of digital archaeological reconstruction on a detailed level from theory to application. This research field has multiple possibilities to be applied in various locations. It is important to conduct future research in this field to explore more of what virtual reality can offer to the field of archaeology. This should be done following the international charters and recommendations discussed in chapter 2 to ensure no negative impact or misinterpretation will be conducted on the history of archaeological sites.

10. APPENDIX

A.1: Interviews with Experts

INTERVIEW

THEORIZING THE UNCERTAINTY OF DIGITAL RECONSTRUCTIONS

INTERVIEWER

FARIDA WAHEED

PhD Researcher at the School of Architecture Design and the Built Environment

NOTTINGHAM TRENT UNIVERSITY

1

- The main purpose of this study is to investigate the subjectivity of archaeological and historic reconstructions and the role that digital technologies can have in virtualizing this uncertainty
- The interview is divided into four sections
- A number of images and a brief introduction will be presented before each section in order to introduce the participant to the research context
- The images presented are from previous research work and are just examples for ellaboration
- The interview should take around 45 to 60 minutes

NOTTINGHAM TRENT UNIVERSITY

2

SECTION 1:

Archaeological Reconstructions are based on different evidence and data types

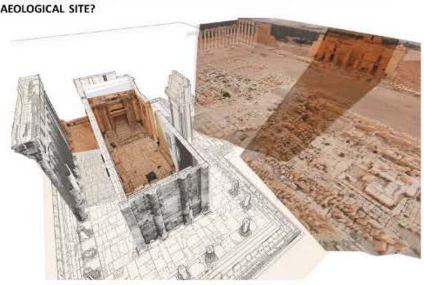
Different Types of Evidence used in the reconstruction

Digital Reconstruction of Karanis City, Ancient Egypt, Fayoum

Source: Elgewely, E., 2017. 3D Reconstruction of Furniture Fragments from the Ancient Town of Karanis. *Studies in Digital Heritage*, 1 (2), 409-427.

3

1- WHAT IS THE METHODOLOGY THAT YOU FOLLOW WHEN YOU RECONSTRUCT AN ARCHAEOLOGICAL SITE?



4

2- WHAT ARE THE TYPES OF EVIDENCE AND DATA THAT YOU USE IN ORDER TO RECONSTRUCT AN ARCHAEOLOGICAL SITE?

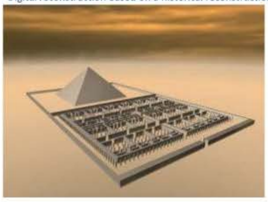
5

3- DO YOU RELY ON YOUR PREVIOUS KNOWLEDGE OF THE HISTORIC CONTEXT IN RECONSTRUCTING PARTS OF THE BUILDING THAT LACK EVIDENCE?

6

4- DO YOU RELY ON PREVIOUS RECONSTRUCTION ATTEMPTS WHETHER HISTORIC OR CONTEMPORARY AS A VALID REFERENCE?

Digital reconstruction based on a historical reconstruction



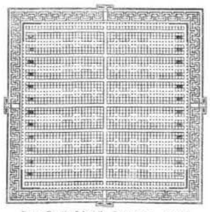


Fig. 3.—Egyptian Labyrinth. Restored Plan. (Canina.)

Source: Shiode, N. and Grajetzki, W., 2000. A virtual exploration of the lost labyrinth: developing a reconstructive model of Hawara Labyrinth pyramid complex. Centre for Advanced Spatial Analysis (UCL).

7

SECTION 2:

There are different approaches followed by archaeologists in the interpretation and reconstruction of archaeological sites

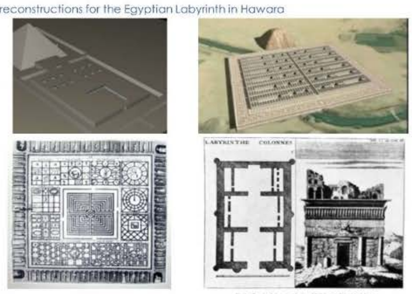
Different reconstructions of the city of Nimrud

Sources: https://www.theguardian.com/commentisfree/2016/nov/17/rebuilding-nimrud-atone-sins-west-isis-destruction
https://www.metmuseum.org/metmedia/video/collections/ancient-near-eastern-art/northwest-palace-nimrud

8

1-DO YOU THINK ARCHAEOLOGICAL INTERPRETATIONS ARE SUBJECTIVE ?

Different reconstructions for the Egyptian Labyrinth in Hawara



9

2-DO YOU OFTEN ENCOUNTER SEVERAL INTERPRETATIONS TO AN ARCHAEOLOGICAL SITE ?

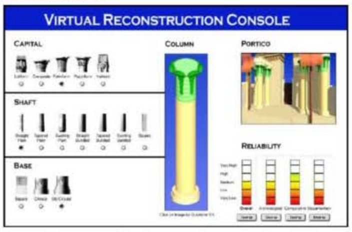
Two reconstructed models representing different Interpretations for the same site

Source: Roussou, M. and Drettakis, G. 2003. Photorealism and Non-Photorealism in Virtual Heritage Representation In: First Eurographics Workshop on Graphics and Cultural Heritage. Eurographics,

10

3-IF YOU CONSIDER TWO OR MORE VALID INTERPRETATIONS DO YOU ATTEMPT TO PRESENT ONLY ONE OR ALL OF THEM?

A virtual reconstruction console representing different alternatives for the column design in a digital reconstruction of an archaeological site



Source: Kensek, K.M., Dodd, L.S. and Cipolla, N. 2004. Fantastic reconstructions or reconstructions of the fantastic ? Tracking and presenting ambiguity, alternatives, and documentation in virtual worlds. Automation in Construction. 13(2), pp.175–186.

11

4-DO YOU FIND IT USEFUL TO DISCUSS YOUR INTERPRETATIONS WITH YOUR PEERS AND WHY?

Source: Scan Pyramids Project (http://www.scanpyramids.org/)

12

SECTION 3:

EACH RECONSTRUCTION PROJECT WILL DEPEND ON DIFFERENT TYPES OF EVIDENCE AND EACH TYPE OF EVIDENCE CARRIES A DIFFERENT DEGREE OF IMPORTANCE

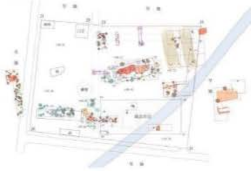


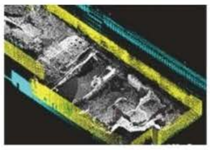
Figure 1. Excavated Area of Dahecun *Archaeological Site, Henan, China*

Source: Jinliang, X., et al., 2013. A Reconstruction and Representation System for 3D Digital Archaeological Documentation – A Case Study of Dahecun Archaeological Site in China . 4 (8).

13

1-DOES STRUCTURAL EVIDENCE GIVE YOU SECURITY IN GENERATING AN ARCHAEOLOGICAL RECONSTRUCTION AND HOW?

Documentation of foundations in an archaeological site



Source: Jinliang, X., et al., 2013. A Reconstruction and Representation System for 3D Digital Archaeological Documentation – A Case Study of Dahecun Archaeological Site in China . 4 (8).

14

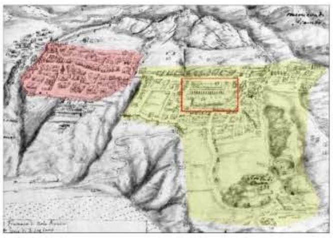
2-DO YOU TRY TO UNDERSTAND THE FUNCTION OF THE BUILDING (I.E. WHAT IT WAS USED FOR) AND WHY?

15

3-DO YOU CONSIDER ARTEFACTS AS AN IMPORTANT TYPE OF EVIDENCE FOR ARCHAEOLOGICAL RECONSTRUCTIONS AND WHY?

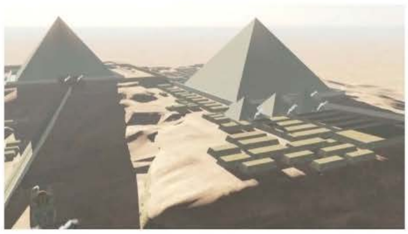
16

4-DO YOU OFTEN BASE YOUR INTERPRETATION ON THE SURROUNDING TOPOGRAPHY OF THE AREA?



17

5-DO YOU RELY ON SIMILAR STRUCTURES TO ESTABLISH A LAYOUT OF THE SITE?



18

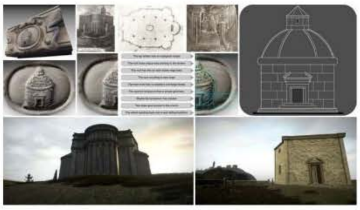
6-TO WHAT DEGREE DOCUMENTED STRUCTURES FROM THE SAME ERA INFLUENCE YOUR INTERPRETATION?

19

7-DO YOU OFTEN CHANGE YOUR INTERPRETATION OF THE STRUCTURAL FEATURES WHEN FACED WITH CONTRADICTORY CONTEXTUAL COMPARISONS?

20

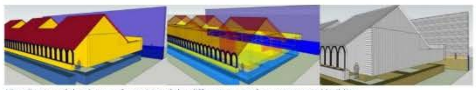
8-DO YOU CHANGE YOUR INTERPRETATION OF THE STRUCTURAL FEATURES IF TEXTUAL EVIDENCE SUGGESTS IT?



21

SECTION 4:

DIGITAL TECHNOLOGIES AND VIRTUAL REALITY OFFER THE POSSIBILITY TO REPRESENT DIFFERENT INTERPRETATIONS OF THE SAME ARCHAEOLOGICAL SITE



Visualization of the degree of certainty of the different parts of a reconstructed building

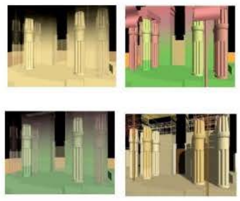
22

SECTION 4:

1-WHAT ARE THE TECHNOLOGIES THAT YOU USE IN THE DIGITAL RECONSTRUCTION OF ARCHAEOLOGICAL SITES?

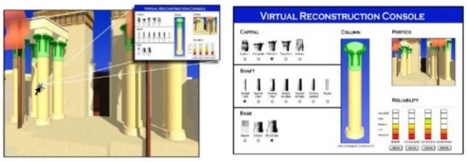
23

2-WHAT DO YOU THINK OF USING VIRTUAL REALITY IN THE RECONSTRUCTION OF ARCHAEOLOGICAL SITES?



24

3-HOW DO YOU THINK VIRTUAL REALITY AS A TECHNOLOGY COULD BE USED TO REPRESENT DIFFERENT INTERPRETATIONS OF THE SAME ARCHAEOLOGICAL SITE?



25

A.2: Surveys with Users

Evaluating Using Virtual Reality in Archaeological Reconstructions

Virtual Reality may help me get more information about a reconstructed archaeological site

	1	2	3	4	5	
Strongly Agree	○	○	○	○	○	Strongly Disagree

Using Virtual Reality may help get access to information about an archaeological site more quickly

	1	2	3	4	5	
Strongly Agree	○	○	○	○	○	Strongly Disagree

Using similar virtual reality experiences may increase my interest in archaeological sites

	1	2	3	4	5	
Strongly Agree	○	○	○	○	○	Strongly Disagree

I think virtual reality was easy to use

	1	2	3	4	5	
Strongly Agree	○	○	○	○	○	Strongly Disagree

I think that my interaction with the virtual reality experience was clear and understandable

	1	2	3	4	5	
Strongly Agree	○	○	○	○	○	Strongly Disagree

I think with time I will be skilful in using similar virtual reality experiences

	1	2	3	4	5	
Strongly Agree	○	○	○	○	○	Strongly Disagree

I have the required knowledge to use virtual reality to be informed about archaeological sites

	1	2	3	4	5	
Strongly Agree	○	○	○	○	○	Strongly Disagree

Virtual reality is similar to other types of technology I use to be informed about archaeological sites

	1	2	3	4	5	
Strongly Agree	○	○	○	○	○	Strongly Disagree

I will need help from others while facing difficulties using virtual reality to be informed about archaeological sites

	1	2	3	4	5	
Strongly Agree	○	○	○	○	○	Strongly Disagree

Using virtual reality in archaeological sites and museums can be fun

	1	2	3	4	5	
Strongly Agree	○	○	○	○	○	Strongly Disagree

I felt like I am in control of the virtual reality experience

	1	2	3	4	5	
Strongly Agree	○	○	○	○	○	Strongly Disagree

I felt nervous through the virtual reality experience

	1	2	3	4	5	
Strongly Agree	○	○	○	○	○	Strongly Disagree

I felt insecure about my ability in using the virtual reality experience

	1	2	3	4	5	
Strongly Agree	○	○	○	○	○	Strongly Disagree

I was afraid to use the virtual reality experience for fear of making mistakes that I can't correct

	1	2	3	4	5	
Strongly Agree	○	○	○	○	○	Strongly Disagree

The virtual reality user interface was clear

	1	2	3	4	5	
Strongly Agree	○	○	○	○	○	Strongly Disagree

The virtual reality user interface was visually appealing

	1	2	3	4	5	
Strongly Agree	○	○	○	○	○	Strongly Disagree

The virtual reality user interface was interactive

	1	2	3	4	5	
Strongly Agree	○	○	○	○	○	Strongly Disagree

Virtual Reality applied to archaeological sites could be credible

	1	2	3	4	5	
Strongly Agree	○	○	○	○	○	Strongly Disagree

Virtual Reality applied to archaeological sites could be reliable

	1	2	3	4	5	
Strongly Agree	○	○	○	○	○	Strongly Disagree

Virtual Reality applied to archaeological sites could be trustworthy

	1	2	3	4	5	
Strongly Agree	○	○	○	○	○	Strongly Disagree

Providing several scenes in the virtual reality experience for the same archaeological site was entertaining

	1	2	3	4	5	
Strongly Agree	○	○	○	○	○	Strongly Disagree

Providing several scenes in the virtual reality experience for the same archaeological site was confusing

	1	2	3	4	5	
Strongly Agree	○	○	○	○	○	Strongly Disagree

Integrating multimedia into the virtual reality experience such as text , sound and images was informative

	1	2	3	4	5	
Strongly Agree	○	○	○	○	○	Strongly Disagree

Integrating multimedia into the virtual reality experience such as text, sounds and images was complicated

	1	2	3	4	5	
Strongly Agree	○	○	○	○	○	Strongly Disagree

There could be several reconstructions of the same archaeological site

	1	2	3	4	5	
Strongly Agree	○	○	○	○	○	Strongly Disagree

Virtual Reality can present the same archaeological site in different ways

	1	2	3	4	5	
Strongly Agree	○	○	○	○	○	Stongly Disagree

Using virtual reality to present different reconstructions (imaginations) of the same archaeological site is confusing

	1	2	3	4	5	
Strongly Agree	○	○	○	○	○	Strongly Disagree

Presenting different reconstructions (imaginations) of the same archaeological site using virtual reality helped me learn more about the archaeological site

	1	2	3	4	5	
Strongly Agree	○	○	○	○	○	Strongly Disagree

Virtual reality enabled me to explore archaeological sites in way I would not be able to explore without it

	1	2	3	4	5	
Strongly Agree	○	○	○	○	○	Strongly Disagree

I would like to use virtual reality in archaeological sites and museums

	1	2	3	4	5	
Strongly Agree	○	○	○	○	○	Strongly Disagree

I will use virtual reality in archaeological sites and museums if it will be available

	1	2	3	4	5	
Strongly Agree	○	○	○	○	○	Strongly Disagree

I classify my level of knowledge related to archaeology as

	1	2	3	4	5	
Very good	○	○	○	○	○	Very bad

I classify my level of knowledge related to how to use virtual reality as

	1	2	3	4	5	
Very Good	○	○	○	○	○	Very Bad

Was this your first time to try experiencing virtual reality

- ◯ Yes
- ◯ No

Age

- ◯ 0-14
- ◯ 15-19
- ◯ 20-29
- ◯ 30-39
- ◯ 40-49
- ◯ 50-59
- ◯ 60-69
- ◯ 70-79

Level of Education

- ◯ Middle and High School
- ◯ Master's Degree
- ◯ Bachelor's Degree
- ◯ PhD

Job/Education

- ◯ Architecture and Construction
- ◯ Environment, Agriculture, Food and Natural Resources
- ◯ Media, Arts, Audio/Video Technology and Communications
- ◯ Education and Training
- ◯ Government and Public Administration
- ◯ Hospitality and Tourism
- ◯ Information Technology
- ◯ Engineering and Manufacturing
- ◯ Business Management and Administration
- ◯ Accountancy, Banking and Finance
- ◯ Health Care
- ◯ Leisure, Sports and Tourism
- ◯ Charity and Voluntary Work
- ◯ Creative Arts and Design
- ◯ Other:

You may use this space for comments and suggestions

Your answer

Submit

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